

Application of computer methods in music composition using smart nanobeams

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Abstract. The paper considers one of the new applications of computer methods in music composition, using smart nanobeams—an integration of advanced computational techniques with new, specially designed materials for enhanced performance capabilities in music composition. The research applies some peculiar properties of smart nanobeams, embedded with piezoelectric materials that modulate and control sound vibrations in real-time. The study is conducted to determine the effects of changes in the length, thickness of nanobeams and the applied voltage on acoustical properties and the tone quality of musical instruments with the help of numerical simulations and optimization algorithms. By means of piezo-elasticity theory, different governing equations of nanobeam systems can be derived, which are solved by the numerical method to predict the dynamic behavior of the system under different conditions. Results show that manipulation of the parameters allows great control over pitch, timbre, and resonance of the instrument; such a system offers new ways in which composers and performers can create music. This research also validates the computational model against available theoretical data, proving the accuracy and possible applications of the former. The work thus marks a large step towards the intersection of music composition with smart material technology, and, when further developed, it would mean that smart nanobeams could revolutionize the process for composing and performing music on these instruments.

Keywords: music composition; nano; numerical method; smart beam

1. Introduction

The meeting point of technology and art has opened completely new frontiers in creative expression, and perhaps one of the most interesting recent trends has been the application of advanced computational methods to the process of musical composition. At this juncture of technology and creativity lie sophisticated tools that further the artistic process beyond known realms of innovation. One of the promising avenues in this domain has to do with smart nanobeams, in which advanced nanotechnology is combined with structural engineering to devise some state-of-the-art ways of composing and experiencing music.

Smart nanobeams represent the class of structures implementing nanotechnology for active and precision control of the mechanical properties. These can work dynamically when excited through external electrical fields and hence can generate multiple vibrations and sounds. Availing these advanced materials, the composers and researchers can explore new methods of sound generation and manipulation, extending the traditional music composition (Lü *et al.* 2024, Zhao *et al.* 2023, Li *et al.* 2024l, Liu *et al.* 2024, Zhang *et al.* 2023).

The literature provides a good review of the background for understanding the behavior and applications of smart

nanobeams and related materials. One such example is that of Berghouti *et al.* (2019), who have investigated the vibration analysis of nonlocal porous nanobeams made from functionally graded materials showing enhanced vibrational characteristics. In the same line, Dong *et al.* (2020) have investigated nonlinear thermomechanical buckling of sandwich FGM plates, by emphasizing the complex interaction between the mechanical and thermal effects. Hirane *et al.* (2021) presented some aspects of static and free vibration analysis of functionally graded sandwich plates by employing a layerwise finite element formulation in order to catch the influence of material grading on vibration behavior. Then, Mudhaffar *et al.* (2021) further studied the hygro-thermo-mechanical bending behavior of advanced functionally graded ceramic-metal plates with a focus on the role of viscoelastic foundations in modifying the structural responses. In turn, nonlinear vibration in fluid-corrugated sandwich functionally graded cylindrical shells was considered by Nguyen *et al.* (2020), furthering knowledge about complex vibrational modes. Nitn *et al.* (2020) studied the cylindrical shells made from composite materials that were based on the application of Flügge-Lur'e-Bryne theory. In this respect, Topkaya and Solmaz (2018) also presented an investigation into behaviors of honeycomb sandwich composites under low-velocity impact, and provided some essentials on material responses related to dynamic conditions. Torres-Jiminez and Rodriguez-Cristerna applied metaheuristic post-optimization techniques to covering arrays, which might be relevant in optimizing

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material performance. Wen *et al.* (2017) discussed a TripleSat constellation intended for geospatial data services. Advanced material applications in data modeling have gone further and are well-explained in their work. The dynamic buckling in polymer-carbon nanotube-fiber composites was investigated by Zarei *et al.* (2017a, b) with extensive discussion of their hygrothermal environment behaviors. Zhao *et al.* (2017) and Allahyari *et al.* (2024) as well as Darihk *et al.* (2023), Farrokhian (2023) have proposed a new kernel method for hyperspectral image feature extraction, hence advanced data analysis techniques applicable to material studies. It thus provides the broad backdrop against which to realize the revolutionary possibilities smart nanobeams offer for composition through controlled dynamic deflection. The result of this study will be to bridge the gap in the interdisciplinary area of material science and music composition by allowing new tools that composers and performers can use in creating and controlling musical output with unprecedented precision, using advanced computational methods and smart materials.

There are several advantages in merging computer methods into this field. Advanced computational algorithms can model and simulate smart nanobeams showing highly accurate behavior, thus, detailed optimization of acoustic properties becomes possible. By applying it, composers can play with complex soundscapes and interactive musical environments that were previously unreachable. This is the application of computer methods in music composition using smart nanobeams. Part of what will be intended from these technological innovations will involve creating new musical experiences and newer insights in compositional techniques and expanding the traditional music theory limits. This research merges the precision of nanotechnology with the flexibility of computational tools in the hope of furthering the development of new artistic practices and offering insights into the creative process in musical composition.

2. Model of smart nanobeams in music composition

Schematic of computer methods in music composition with smart nanobeams is presented in Fig. 1. The computer, running music composition software is connected by arrows to the smart nanobeams, representing algorithmic control over the vibration properties of the nanobeams. Sensors and actuators attached provide for monitoring and adjusting the behavior of the nanobeams - further providing a feedback signal back to the computer. Musical notes and sound waves flow out from the speakers, while the resulting musical output from the interaction of smart nanobeams and computational methods are expressed through the course of interaction. Nanobeams, which are represented as flexible structures, adapt to the algorithms in influencing the process of composition. The smart nanobeam has length of L and thickness of h .

The Euler model, sometimes also referred to as Euler-Bernoulli beam theory, defines the displacement field based upon the assumption that plane sections remain plane and perpendicular to the neutral axis after deformation. In the context of this classic model, one will allow a simplification

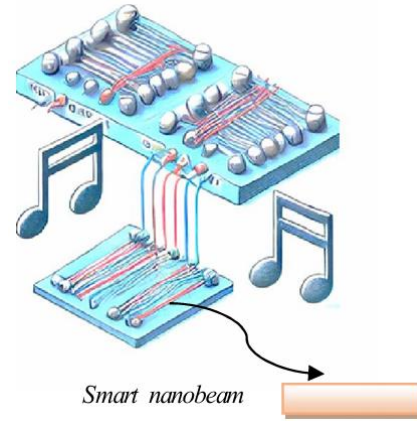


Fig. 1 The schematic view of the smart nanobeams in music composition

in the analysis for slender beams by taking into account that the effects of shear deformation become null. In general there is a displacement of the Euler model along the length of the beam, the field consists of an axial displacement and a transverse displacement or deflection in the direction perpendicular to the beam. The axial displacement is taken to be proportional to the distance from the neutral axis in a linear fashion, the transverse displacement depends upon the amount of bending of the beam. This makes the deformation field a function of curvature in the beam, and one can subsequently compute the bending stresses and strains. While the Euler model can be very powerful for slender beams and small deflections, it may not remain very accurate for thicker beams, or when shear deformation and rotational effects are considerable. This theory has below form (Bakhshandeh Amnieh *et al.* 2018, Baseri *et al.* 2016, Bilouei *et al.* 2018, Hajmohammad *et al.* 2021):

$$u_1(x, z, t) = u(x, t) - z \frac{\partial w(x, t)}{\partial x} \quad (1)$$

$$u_2(x, z, t) = 0 \quad (2)$$

$$u_3(x, z, t) = w(x, t) \quad (3)$$

where u and w are the displacements. The strain relations are:

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} - z \frac{\partial^2 w}{\partial x^2}, \quad (4)$$

Smart nanobeams are usually modeled by the piezoelectricity theory, which is interlinked with elastic and piezoelectric effects. Piezoelectric materials possess the intriguing property that when being mechanically deformed, they produce an electric charge-direct piezoelectric effect-or the inverse process, they deform mechanically when subjected to an electric field-converse piezoelectric effect. Such materials are perfect for sensors, actuators, and energy harvesting applications where they control vibrations or respond dynamically to different external excitations.

The theory of piezoelectricity embeds the governing equations of linear elasticity with the electro-mechanical coupling properties of piezoelectric materials. To this aim,

the theory will define the way according to which, for a smart nanobeam, the mechanical deformation (bending and stretching) influences the electrical response and how the applied electric field can induce mechanical deformation.

The set of fundamental equations that define piezo-electric behavior includes:

A-Mechanical equilibrium equations: These are derived from elasticity theory, which prescribes the stress-strain (σ - ε) relationships of the material. For nanobeams, they describe how the beam deforms under mechanical loads. The basic relations is (Kolahchi *et al.* 2015a, b, 2016a, b):

$$[\sigma] = [C]\{\varepsilon\} - [e]\{E\}, \quad (5)$$

where C is the elastic and e is the piezoelectric constants.

B-Electric field equations: These are those which describe how the electric field is generated or changed by material deformation (D - E). The basic relations is:

$$[D] = [e]\{\varepsilon\} - [\epsilon]\{E\}, \quad (6)$$

where ϵ is dielectric constant. The electric potential is:

$$\Phi(x, z, t) = -\cos(\pi z/h) \varphi(x, t) + \frac{2V_0 z}{h}. \quad (7)$$

where V_0 is the electric voltage. The energy method had the capability to analyze a system whereby it could incorporate the contribution of potential energy, kinetic energy, and work done from an external agency. Potential energy is a description of energy that is stored in a system due to its configuration or position. This may be gravitational or elastic potential energy. Kinetic energy is the contribution from the motion of the parts composing the system, obtained from their respective masses and velocities. The external work encompasses all such work done on or by the system due to the forces in an external environment that raises or lowers the total energy of a system. Summing these energies yields an equation that describes the dynamic behavior of the system such that the total energy, comprised of potential and kinetic contributions, and the work done from the external sources, is conserved, and the response of the system under these conditions may be predicted. The energies are:

$$U = \frac{1}{2} \int_V (\sigma \varepsilon - DE) dV. \quad (8)$$

$$K = \frac{\rho}{2} \int_V [(\dot{u}_1)^2 + (\dot{u}_2)^2 + (\dot{u}_3)^2] dV. \quad (9)$$

$$W = \int_x Force w dx. \quad (10)$$

Hamilton's principle states that the true path of a system is such that the time integral of a Lagrangian function, which is the difference between kinetic and potential energy, is at a minimum. In this regard, it can offer a general framework through which the equations of motion for dynamic systems can be derived by setting the variation of the action integral equal to zero. Based on this method, we have:

Equation 1:

$$\delta u: \frac{dN}{dx} = m_0 \ddot{u} \quad (11)$$

Equation 2

$$\delta w: \frac{\partial^2 M}{\partial x^2} - Force = m_0(\ddot{w}_b + \ddot{w}_s) - m_2 \frac{\partial^2 \ddot{w}_b}{\partial x^2} \quad (12)$$

where

$$(N, M) = \int_A (1, z) \sigma_x dA \quad (13)$$

In this section, orthogonal polynomial functions are used in the Rayleigh-Ritz method of the finite element method. First of all, orthogonal polynomial functions are explained in detail and then the finite element method assumptions are revisited. Later on, using these orthogonal polynomial functions, the buckling load of the structure is calculated for different boundary conditions. Based on orthogonal polynomial functions, the shape function of a beam can be presented as follows (Motezaker *et al.* 2021a, b):

$$F = \sum_{m=1}^M A_m f_m(x) \quad (14)$$

where $f(x)$ is to be expressed as orthogonal polynomial functions. It has been demonstrated by Biehet that orthogonal polynomial functions can be generated through the Gram-Schmidt method. To give an example of the latter, consider a function in the x-direction which can be based on a polynomial of degree k: the following relation defines such a function:

$$f_2(x) = [g_0(x) - A_1]f_1(x) \quad (15)$$

$$f_{k+1}(x) = [g_0(x) - A_k]f_k(x) - B_k f_{k-1}(x) \quad k \geq 2 \quad (16)$$

In the above relations, $f_1(x)$ is known as the generating function, and $g_0(x)$ is known as the starting function. In order to determine these functions, boundary conditions at one end of the beam have to be considered. Note that A_k and B_k are constants of the orthogonal polynomial functions, which are found through the use of the following relations:

$$A_k = \frac{\int_0^1 g_0(x) f_k(x) f_k(x) dx}{\int_0^1 f_k(x) f_k(x) dx} \quad (17)$$

$$B_k = \frac{\int_0^1 g_0(x) f_k(x) f_{k-1}(x) dx}{\int_0^1 f_{k-1}(x) f_{k-1}(x) dx} \quad (18)$$

Generally, to obtain these functions, attention has to be paid to the type of boundary conditions. If the initial function $f_1(x)$ is given as a polynomial of degree four, we have:

$$\int_{t_1}^{t_2} \delta \Pi dt = 0 \Rightarrow \int_{t_1}^{t_2} (\delta T - \delta U) dt = 0 \quad (19)$$

In the above relation, the values of the constants are determined from boundary conditions at the ends of the beam. The boundary conditions that are most important follow and the functions required for these end conditions are derived. The functions for all the above boundary conditions are summarized thereafter. This method is based on energy as:

$$\Pi = U - K - W \tag{20}$$

It is then possible to obtain optimal solutions to the problem by extremizing, that is, finding the maximum or minimum of the relevant functional as:

$$\frac{\partial \Pi}{\partial A_m} = 0, \quad \frac{\partial \Pi}{\partial B_m} = 0, \quad \frac{\partial \Pi}{\partial C_m} = 0 \tag{21}$$

3. Numerical results

Numerical simulations were performed to study, for application to music composition, effectiveness, and performance of smart nanobeams. Emphasis is given to the frequency response analysis, understanding the characteristics of modes, and the overall impact musical composition would receive by use of computer methods to control such nanobeams.

Fig. 2 shows the effect of voltage on dynamic deflection for the composing of music. As analyzed from Fig. 2, the use of negative voltage in smart nanobeams or structural elements results in reduced amount of deflection, in other words, which this reduces the magnitude of deflection, and hence alteration of vibration characteristic of an element changes the sound it can produce in an aggregated form. More specifically, negative voltage acts on those material features as stiffness and tension. In this way, the amplitude of vibrations can be reduced, which may finally result in changing the pitch and quality of the sound. In this respect, it may prove an efficient tool for fine-tuning and control in the hands of composers and designers. This, in turn, offers subtle nuances of acoustic performance for the musical instrument or composition through cautious variations in voltage.

Fig. 3 shows the impact of smart nanobeams on dynamic deflection in the composition of music. It can be understood from the data that there is a significant increase in dynamic deflection when using smart nanobeams compared to traditional materials. The main improvement in deflection is because of the higher properties which smart nanobeams possess, one of these properties being their capability to respond dynamically with respect to external stimuli, such as a change in voltage. Directly influencing the amplitude and quality of the vibrations produced, further deflection was possible by changes in the stiffness or even damping characteristics of the smart nanobeams. Dynamic deflection could now be greater, allowing a sensitivity and expression in the musical composition never before possible with other materials by composers and designers. It can open a new page in the art of designing musical instruments and sound synthesis, since, for the first time, deflection can be modulated with such precision.

Fig. 4 shows the effects of CC and SS boundary conditions on the dynamic deflection of a nanobeam in musical composition. Analysis indicates that, for CC boundary conditions, a nanobeam shows a dynamic displacement that is about 59% less. Such a larger deflection decrease arises from the greater bending rigidity inherent in the clamped-clamped configuration. The clamped-clamped boundary

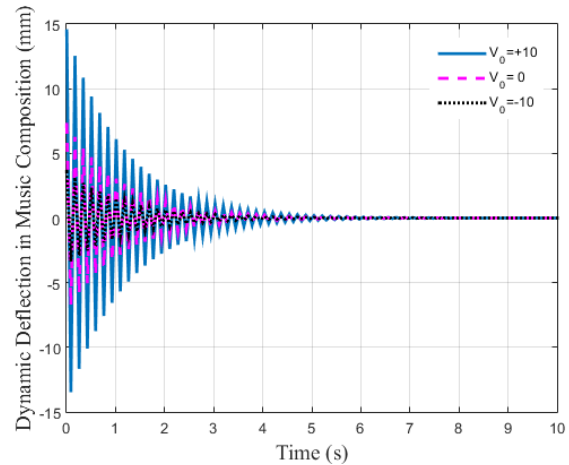


Fig. 2 The influences of voltage on the dynamic deflection in music composition

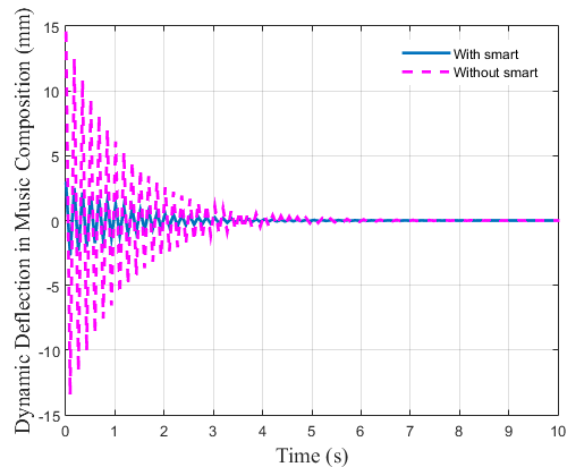


Fig. 3 The influences of smart nanobeam on the dynamic deflection in music composition

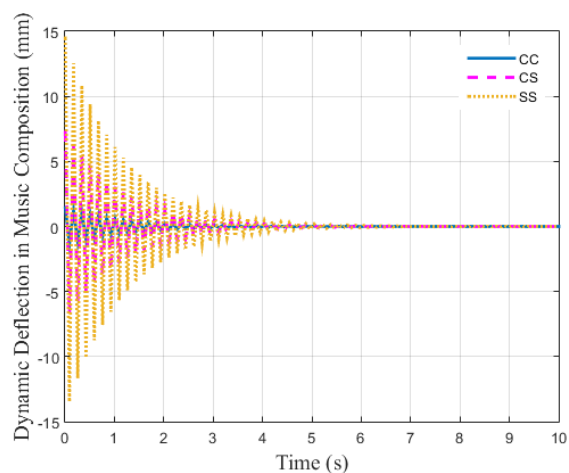


Fig. 4 The influences of boundary condition on the dynamic deflection in music composition

condition hinders the mobility at both the ends of the beam, making it to show more resistance against bending due to dynamic loads. This makes the nanobeam vibrate with

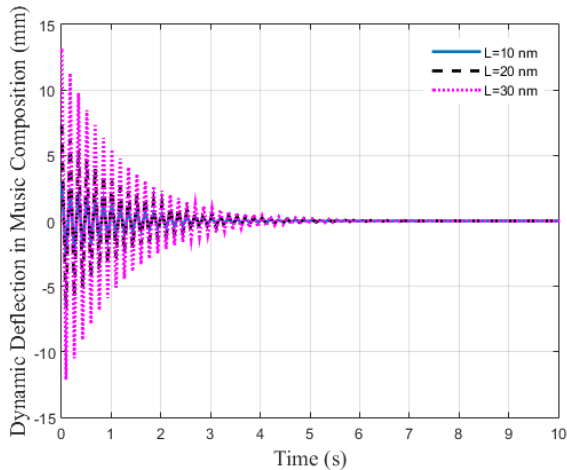


Fig. 5 The influence of smart nanobeam length on the dynamic deflection in music composition

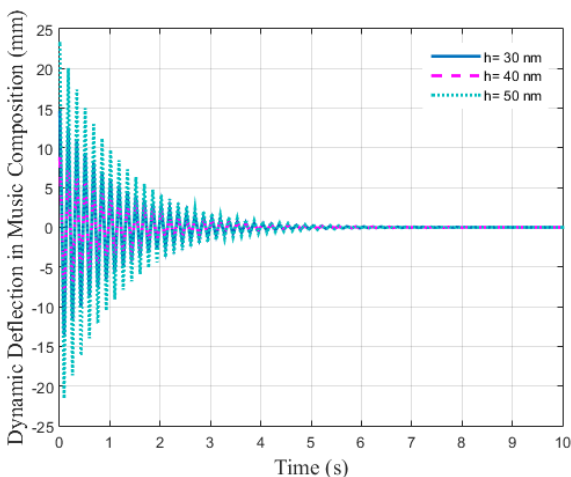


Fig. 6 The influence of smart nanobeam thickness on the dynamic deflection in music composition

reduced amplitude, which will have a direct influence on the acoustic properties of the sound generated. This may lead to changes in the pitch and timbre of the musical output and therefore constitutes a tool for designers and composers to effectively fine-tune the acoustic characteristics of an instrument with high precision. These results highlight the importance of boundary conditions in the process of tuning dynamic performance of smart nano-beams towards optimum sound quality and music performance.

Fig. 5 presents the effect of smart nanobeam length on dynamic deflection in the composition music. It is seen from the results that the dynamic deflection increases with increasing the length of the nanobeam. The justification of the above discussion can be given from the physical point of view based on the principle of structures: in a fixed condition by increasing the length of the nanobeam, the overall stability and rigidity of the nanobeam decrease. As the nanobeam length increases, the stiffness or resistance of this nanobeam against bending and oscillations decreases. Consequently, larger deflections occur in the case of dynamic loads. These further displacements increase the amplitude of the vibration and thus highly affect the

resulting sound produced by the nanobeam. Therefore, with respect to the length of the nanobeam, the composers or designers can make a change that could lead to changes in the acoustics of the produced musical output: pitch and timbre. It is the possibility of fine-tuning that gives these parameters significant control over the sound quality and performance of musical instruments, hence showing the criticality of the nanobeam dimensions to music composition and sound synthesis.

Fig. 6 presents the influences of smart nanobeam thickness on dynamic deflection in music composition. It is observed from the results that dynamic deflection decreases with the increase in the nanobeam thickness. The reasons may be that increased nanobeam thickness improves structural rigidity and stiffness. Because of this, the resistance of the nanobeam to bending and to deformation improves with increased thickness, thus reducing the amplitude of the dynamic displacements. Reduced deflection therefore translates into more controlled and fine vibration characteristics-aspects that, in turn, affect the quality and stability of the resulting sound. A nanobeam of larger thickness would contribute to the overall stability of the structure and allow finer adjustments in musical parameters such as pitch and tone. This possibility will allow designers and composers to better control the performance of musical instruments and the sound synthesis by effectively tailoring the acoustic properties of the nanobeam through the variation of its thickness.

4. Conclusions

In this paper, an application of smart nanobeams has been brought to novel music composition. Advanced computational techniques are merged with unique features of smart materials for enhancing musical performance. The smart nanobeams incorporate piezoelectric materials, and through those, modulate and control in real time the vibrations that produce sound. Indeed, it opens a new frontier with unimagined precision in quality and musical tone. Numerical simulations and optimization algorithms here provide an insight into how dynamic deflection is affected by multiple parameters. These findings show that negative voltage applied to smart nanobeams decreases dynamic deflection, hence changing the vibration characteristics and thereby probably the pitch and quality of the sound produced. This thus gives a potent tool to the composers and designers in making voltage adjustments to fine-tune acoustic performance for nuanced and expressive musical composition. Indeed, this study explains that smart nanobeams could achieve much larger dynamic deflection than conventional materials, since they are far more sensitive to external stimuli. With greater deflection, the amplitude of the vibrations is increased, and thus control over the vibration improves. It opens new horizons in the design and synthesis of musical instruments. Furthermore, the application of boundary conditions such as CC and SS to the dynamic deflection points out that the structure configuration is of major importance during the tuning of the acoustic performance of smart nanobeams. For instance, CC boundary conditions provide a much smaller deflection

since it has a larger bending rigidity, hence it provides the precise sound feature modulation. The same research points out the variations that occur on the nanobeam length and thickness with respect to the dynamic deflection. With increasing nanobeam length, the deflection increases, which influences the amplitude of oscillations and thus the resulting sound.

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