Stability, Reliability, Compatibility: Reviewing 40 Years of DMI Design

John Sullivan
IDMIL, CIRMMT
McGill University
john.sullivan2@mail.mcgill.ca

Marcelo M. Wanderley
IDMIL, CIRMMT
McGill University
marcelo.wanderley@mcgill.ca

ABSTRACT

Despite the proliferation of new digital musical instruments (DMIs) coming from a diverse community of designers, researchers and creative practitioners, many of these instruments experience short life cycles and see little actual use in performance. There are a variety of reasons for this, including a lack of established technique and repertoire for new instruments, and the prospect that some designs may be intended for other purposes besides performance. In addition, we propose that many designs may not meet basic functional standards necessary for an instrument to withstand the rigors of real-world performance situations. For active and professional musicians, a DMI might not be viable unless these issues have been specifically addressed in the design process, as much as possible, to ensure trouble-free use during performance. Here we discuss findings from user surveys around the design and use of DMIs in performance, from which we identify primary factors relating to stability, reliability and compatibility that are necessary for their dependable use. We then review the state of the art in new instrument design through 40 years of proceedings from three conferences - ICMC, NIME, and SMC - to see where and how these have been discussed previously. Our review highlights key factors for the design of new instruments to meet the practical demands of real-world use by active musicians.

1. INTRODUCTION

The advent of real time digital audio processing and availability of low cost, robust computational resources, electrical components and sensor technologies have led to the ongoing design and development of a stunning variety of new digital musical instruments and interfaces for musical performance [1]. As evidenced by the establishment of dedicated research laboratories, academic programs, and conferences with specific instrument/interface design and performance tracks, the design of DMIs is a popular and meaningful domain within music technology research.

However, despite the wide array of new instruments and interfaces that are developed and demonstrated, many see limited use in real-world performances and there are few examples of DMIs that have experienced long-term use. Reasons suggested for this include a lack of skilled and/or professional DMI performers and "too little striking music" being made [2], absence of established instrumental techniques and repertoire and insufficient forms of musical notation for new instruments [3], and varying motivations by instrument designers [4].

In addition to these, we consider a more fundamental set of operational requirements that are imperative to performing with any musical instrument and propose that basic system quality issues such as stability and reliability also preclude some new DMIs from successful and continued use. For active and professional music performers, whose time is stretched between concerts, rehearsals, travel and more, and who may rely on their instruments for their livelihood, these issues are all the more critical. New technologies will likely be quickly discarded or passed over if they suffer from hardware or software instability, durability problems, or lack compatibility with other instruments and performers.

Research on the design of new instruments and interfaces has provided a variety general frameworks and guidelines to aid designers in the creation of new instruments (see [5] for a review). There are also some well-known touchstones in the literature that provide heuristic principles for quality in DMI design such as those proposed by Cook in [6] and updated in [7]. Additionally, case studies in design evolution of instruments such as the Continuuum [8] have highlighted aspects of design for stability and reliability in performance.

As the field of DMI design continues to grow and mature, quality issues become all the more important to consider. In [9], Buxton asserted that *artistic spec* – encompassing the domain of musical instrument and interface design – was the hardest level of design to achieve, more so than *standard* and *military* spec. Advancing technology, improved design methodologies and an ever-growing body of research and literature are just some factors of many that have led to increasingly powerful, complex and capable instruments and interfaces [10].

While historically there seems to have been a lack of systematic research to address these basic quality issues, it is an area that is receiving more attention in recent years. In a review of sensor technologies and signal processing techniques used in new musical interfaces, [11] found that oftentimes new designs were plagued by poor sensor choice and "unsophisticated engineering solutions" that would hinder their reliable use. The authors outline options for better hardware choices and optimized signal processing tech-

Type of musical practice	%
Professional	43%
Hobbyist/Recreational	38%
Student	11%
Instructor/Educator	7%

Table 1. Musical practices of survey respondents

niques like sensor fusion to improve the fidelity of new instrument designs. In addition, a recent report on performance usage of DMIs coming from the NIME conference [4] focuses on instrument builders and the link between design and performance, which we will discuss in Section 2.2.

To help strengthen the link between innovative new instrument design and a diverse body of performers who would use them, we aim to identify specific areas that designers could target to adequately meet basic operational requirements for instruments intended to be used in performance. We begin by considering user survey data from musicians and instrument makers about the use of new instruments in performance, motivations behind the design of new instruments, and factors that influenced the uptake, continued use and abandonment of new technologies for performance. Then we present a detailed analysis from the papers in three main conferences on music and technology, going back over forty years to 1975. The combined scope of the three conferences is essential to cover dozens of indispensable contributions that pre-date the establishment of the NIME conference in 2002 after the initial NIME workshop in 2001 [12], but also to go beyond the NIME aesthetics and address similar works in other important conferences in this field such as SMC and ICMC.

Together, the survey results and literature analysis highlight key focal points regarding the development of new instruments that active musicians would be willing to work with, and are intended to contribute to a larger dialogue about DMI use in performance.

2. USER SURVEYS AND FEEDBACK

2.1 DMI Performers

The basis for this investigation came from a survey conducted by the first author to gain a general understanding of how new digital instruments and interfaces are used across different performance communities [13]. An online questionnaire collected information from performing musicians about their background, training, choice of instruments and styles of music they perform, along with answers to specific questions about DMI use. The survey was interested in capturing a variety of different kinds of performers, which was reflected in the makeup and diversity of respondents. Over 100 responses were received, with nearly half identifying as professional musicians as shown in Table 1. A wide distribution of musical styles was represented with experimental and computer music, rock and pop, and classical the most common, shown in Table 2.

Musical Style	%
Experimental/Avant-Garde/Computer Music	24%
Rock/Popular	22%
Classical	14%
Acoustic/Folk/Country	7%
Jazz/Blues/R&B	7%
Electronic/EDM/House	5%
Religious	2%
TV/Film/Theatrical	2%
Hip Hop/Rap	1%
International/World Music	1%
Country	0%
Other:	15%

Table 2. Musical styles reported by survey respondents

2.1.1 Uptake and Abandonment

The survey took special interest in understanding factors that influence performers' uptake and continued use or rejection of new technology.

As shown in Figure 1, respondents indicated that they commonly learned about new instruments by experiencing them from someone else – a friend, bandmate, or seeing it used live in performance. However many new DMIs are created as prototypes or one-offs and lack the recognition and availability of commercial instruments. This would make them less likely to be introduced to performers and limit their adoption into practice. Furthermore, adoption of new instruments assumes that they have been designed with the intent of having them put into use which, as we discuss in the next section, may not always be the case.

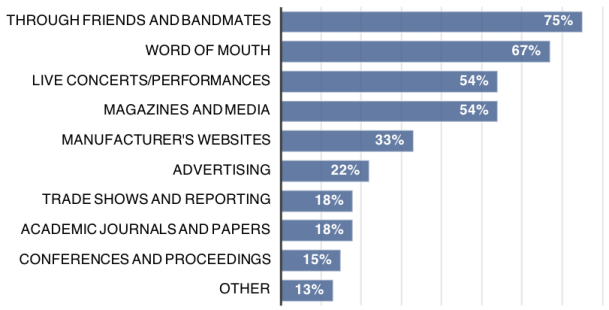

Figure 1. How do you learn about new digital and electronic instruments?

A question about abandoning instruments relates closely to our discussion about quality factors for DMIs in performance, and is shown in Figure 2. Participants were asked if they had stopped using certain DMIs and if so, why. The multiple choice answers presented a variety of issues, from interface and performance issues to personal preference. 11% of respondents reported that they had discontinued using certain instruments because they worked poorly or not at all.

Additionally, over one-third of the respondents wrote in their own answers under the "Other" category. Of these, most cited specific issues that hindered the proper functioning of their instruments:

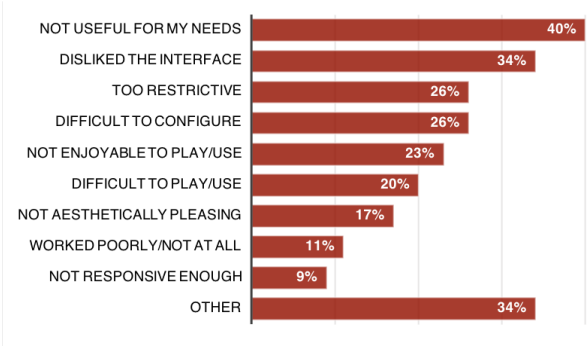

Figure 2. What factors influenced you to discontinue using an instrument or new technology?

- *"Instruments fell apart too easily, and I ran the risk of damaging them beyond repair or during a live performance."*
- *"Age and better tech option"*
- *"Difficult to maintain and keep current with collaborating technology"*
- *"New, better technology"*
- *"Do not run with current OS"*
- *"Cost too much to repair."*
- *"The company stopped firmware updates for it."*

2.2 DMI Makers

Another recent survey polled DMI makers who had presented new instruments and interfaces at the NIME conference between 2010 and 2014 [4]. The objective of this work was to find out what designers' motivations were for creating new DMIs, and to give information about their instruments' current state and use. The survey revealed that most new instruments had experienced little sustained use beyond their initial build and demonstration. Responses showed that often the designers' original motivations were not for performance at all, but for other reasons such as research, technology tests, in-progress prototypes, or academic exercises.

The survey also found that, of the respondents' instruments that were intended for performance, only half of them remained in playable condition. Reasons included lack of time, attention or interest, outstanding hardware and software maintenance issues, and dissatisfaction with the instrument. It also highlights a trend in which the DMI designer is the primary (or only) performer over the instrument's life.

Regarding DMI use in performance contexts, a related survey that polled NIME performers found that most performers had either designed or were closely involved with the design of the instruments that they played [14]. While the integrated role of designer-performer presents interesting possibilities for both design and performance, it may also suggest limitations in the propagation of DMIs into more widespread practices. This topic moves beyond our inquiry here but is an important aspect of the DMI ecosystem to consider and has been discussed in depth in [15], a long-term, multidisciplinary project based on the design and performance with new DMIs.

2.3 Takeaways

User data from these surveys show that lack of use and abandonment of DMIs can be attributed to a variety of reasons. It comes as no surprise that, coming from a research-minded community like NIME, instruments frequently struggle to progress beyond prototype or developmental stages [16]. This is understood not as a failure but an part of ongoing research and design processes that may extend well beyond the life cycle of a single instrument.

Beyond the motivations of the designers and research-oriented focuses that may not include performance, both surveys indicate that the non-functioning of instruments is a common occurrence and cause for instruments to be removed from use. From the responses we found that the following terms loosely characterize the most common issues relating to the basic operational functioning of an instrument: *stability*, *reliability*, and *compatibility*.

By *stability*, we refer to the proper and robust operation of all aspects of an instrument - it should be playable in a dependable state without unreasonable risk of failure. *Reliability* extends the concept of stability over time. An instrument should remain stable, dependable and in good working order over the course of long-term use and designed to withstand the rigors and wear and tear of normal operation throughout the intended life cycle of the instrument. We include topics of maintainability and repairability here as well. Finally, *compatibility* refers to an instrument's capability for integration with and use alongside other instruments, performers, devices, softwares and systems without need for extensive modification or use of special equipment or software. These three areas form the basis of our literature analysis in the next section.

3. TERMINOLOGY IN DESIGN LITERATURE

In order to construct a broad overview of how much attention has been paid to these topics and in what specific contexts, we conducted a linguistic analysis of proceedings from three conferences dedicated to music and computing: the *International Computer Music Conference* (ICMC, 1974-2016), the *International Conference on New Interfaces for Musical Expression* (NIME, 2001 to 2016), and the *International Sound & Music Computing Conference* (SMC, 2004 - 2016). Together the proceedings represent over forty years of published research on music and computing, including DMI design and performance.

3.1 Methodology

The methodology for our review was based on techniques used by Jensenius in his analysis of "gesture" and associated terminology in [17]. First we performed a search through each year of proceedings to return the number of papers containing a set of keywords relevant to our topic.

This was followed by concordance and collocation analyses that yielded a ranked list of terms closely associated with the keywords.

3.2 Paper Selection

The first step in our process was to collect proceedings from the three conferences, which are freely available for download [1] [2] [3].

For NIME, we performed our analysis on the entire collection of proceedings, as the conference is centered around research on new interfaces and instruments for musical expression (including performance). It got its start in 2001 as part of the ACM Conference on Human Factors in Computing Systems (CHI) [4]. Citing the continued evolution of technology and its applications in musical interface design, along with established scholarship and interest in the area of musical expression [1], Poupyrev et al. [18] organized a CHI workshop dedicated to these topics, and NIME was born. Fourteen papers were presented in 2001 (which are included in our analysis here), and the following year NIME expanded into a conference of its own.

The ICMC and SMC conferences cover a wide range of topics relating to music and computing, many of which fall outside the area of instrument design and performance, such as computer music composition, musicology, signal processing, music information retrieval and more. Because of this, we limited our analysis to the papers we considered relevant to our topic. Our selection procedure entailed scanning the title and abstract of each paper and collecting only those that reference novel musical instruments, interfaces and controllers (and more generally performer-instrument interaction), and performance with new musical instruments.

Table 3 shows the complete breakdown of total papers and those included in our review. In total, 2227 papers were included in our search spanning from 1975 to 2016: 665 from ICMC, 1416 from NIME, and 146 from SMC. To condense the large dataset, we present our results in four-year blocks, noting the following adjustments. Proceedings from ICMC 1974 and 1976 are missing from the download archive, and the conference was not held in 1979. Therefore the first four-year block consists of 1975, '77, '78 and '80. In 2014, the ICMC and SMC co-hosted a single conference, with papers assembled into a single volume attributed to both conferences. To spare redundancy they are included in only the ICMC dataset. Finally, we note that SMC's inaugural year was 2004 and is the only year contained in '01-'04 for SMC. Thus the metrics for this block (as in Fig. 3 and 4) are based on a smaller sample size than the other blocks.

3.3 Keyword Occurrence

Our analysis began with a keyword search to identify papers in our corpus that were relevant to our topic. We began with the basic issues we proposed from the user surveys and augmented them with closely related factors to form a list of functional requirements for a DMI used in performance: *stability*, *reliability*, *durability*, *compatibility*, *maintainability* and *robustness*. The terms are far from a comprehensive list of DMI design considerations; instead we are mostly concerned about general quality attributes that characterize successful and trouble-free functioning of instruments through real-world situations and activities that active performing musicians operate in: on and off stage and other performance environments; interfacing with venue sound and multimedia systems, other instruments and players; transporting and storing instruments; and so on.

To automate the search, a shell script was written that returns the number and filenames of papers by year that match a given search query. This methodology made it possible to quickly extract some high-level information and retrieve a focused subset of literature from a large collection that would have been impractical to sort through manually. Our results are shown in Figure 3 as the percentage of papers that contain each of the individual keywords as well as the percentage that contain any of the keywords. The term *maintainability* was removed from the table to preserve space, as it occurred in less than 0.5% of all papers, however it is included in the rest of the analysis.

The same search was run a second time using a lemma list, which included syntactical variations of the same root word. However, we found this not to be useful, as it returned many results unrelated to our topic. For example, the lemma of *reliability* is *rely*, which is commonly used in a wide variety of situations that fall well outside of our concern. Therefore the search was kept with only the specific terms.

The results revealed that the list of terms occurred somewhat infrequently throughout the literature. Across the entire corpus, the most common of the terms, *stability*, occurred in 7.5% of all papers. For the most part, however, we were able to observe a general upwards trend through the more recent years, starting around 2001. The most recent block, 2013 - 2016, shows that around 25% of papers included in our corpus across all conferences contained at least one of the terms.

	ICMC		NIME		SMC	
	All	Inc.	All	Inc.	All	Inc.
1975-1980	138	**27**	—	—	—	—
1981-1984	176	**29**	—	—	—	—
1985-1988	262	**41**	—	—	—	—
1989-1992	451	**51**	—	—	—	—
1993-1996	581	**73**	—	—	—	—
1997-2000	518	**74**	—	—	—	—
2001-2004	473	**56**	137	**137**	18	**9**
2005-2008	745	**127**	346	**346**	159	**40**
2009-2012	518	**104**	480	**480**	290	**47**
2013-2016	567	**83**	453	**453**	268	**50**
Totals:	*4429*	***665***	*1416*	***1416***	*735*	***146***

Table 3. Number of papers from each conference per four-year block and those included in our review (in bold).

[1] https://quod.lib.umich.edu/i/icmc/bbp2372.*
[2] www.nime.org/archive
[3] http://smcnetwork.org/resources/smc_papers
[4] https://chi2018.acm.org/

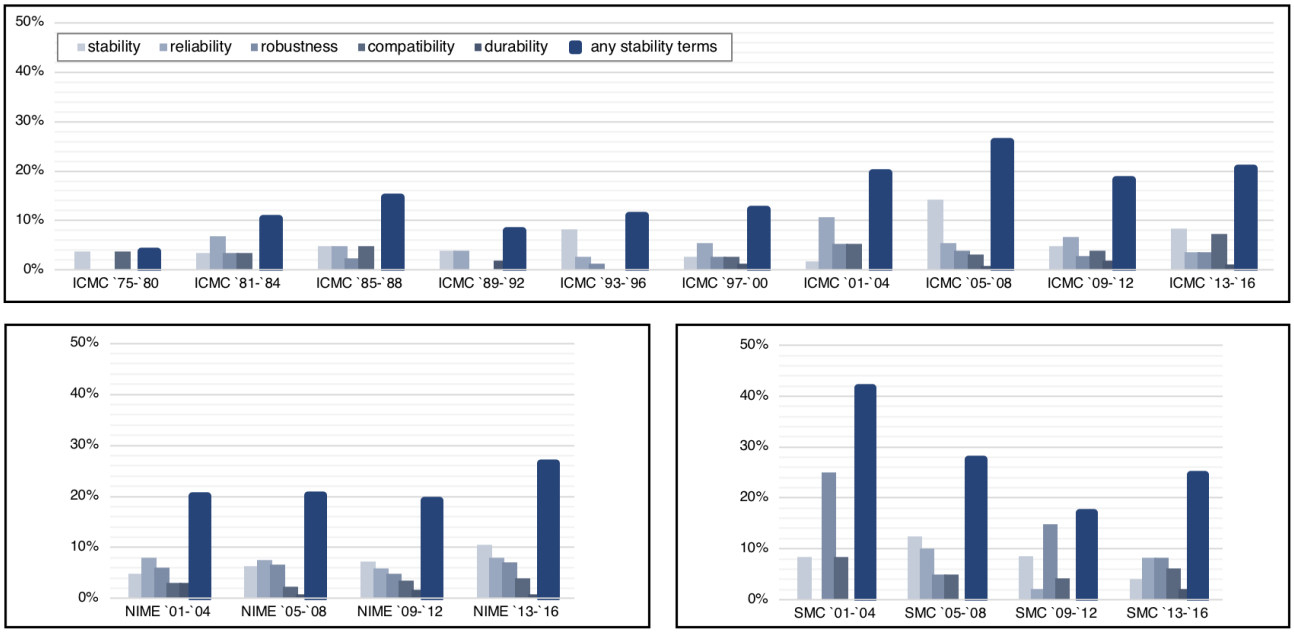

Figure 3. Percentage of papers containing our *quality attribute* keywords for each conference. For each plot, the first five bars indicate the percentage of papers containing individual keywords, while the larger right-most bar indicates the papers that contained *any* of the keywords. See Table 3 for total number of papers included in the search.

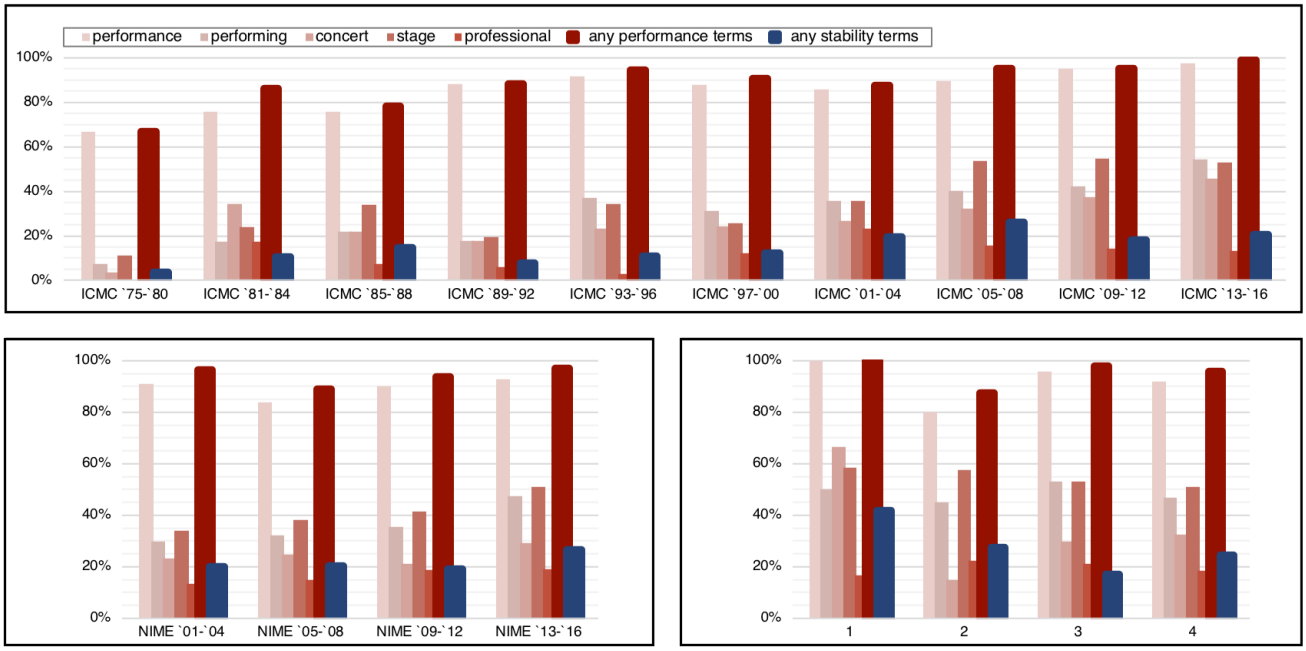

Figure 4. Percentage of papers containing *performance* keywords. For comparison, the smaller rightmost bar indicates the percentage of papers containing *quality attribute* keywords.

Quality	#	Design	#	Usage	#	Function	#	Focus Areas	#
stability	210	system	105	performance	72	expression	25	sensors	59
reliability	124	testing	26	control	72	signal	22	data	38
robustness	112	interaction	26	gesture	38	structure	20	parameters	35
compatibility	58	implementation	18	improve	24	real-time	20	rhythmic	25
durability	27	analysis	15	feature	19	order	19	pitch	20
flexibility	22	development	14	physical	18	output	18	note	20
support	17	requirements	10	live	18	rate	17	hardware	20
usability	14	future	10	performer	15	pattern	17	environment	20
accuracy	14	mapping	9	player	13	electronic	16	tempo	18
condition	13	evaluation	9	playing	10	controller	16	software	18
complexity	13	algorithm	7	operate	9	state	12	latency	18
responsiveness	12	framework	6	musicians	8	input	11	motion	24
safety	9	protocols	5	rehearsal	6	mechanical	9	haptic	15
maintenance	9	properties	5	professional	6	standard	8	network	14
portability	6	HCI	4	experience	6	effective	8	MIDI	14
repairability	4	commercial	4	long-term	5	balance	8	feedback	14

Table 4. Top concordance results, sorted and ranked by category. The original keywords are italicized.

3.3.1 Performance Keywords

For comparison, we ran the search again with a list of performance-related terms: *performance*, *performing*, *concert*, *stage*, and *professional*, shown in Figure 4. Overall, 93% of the all papers contained at least one of the terms, with the word *performance* alone appearing in 89% of all papers. The contrast of these compared to our quality attributes suggests that use of new instruments in performance is a fundamental preoccupation within the research community, yet discussion of the basic, practical qualities an instrument must possess to reliably achieve that goal is less prevalent.

The least common performance keyword occurring in literature was *professional*. This is also an important consideration, as it may suggest that designing for professional use is not currently a strong motivation in the field. However, frequency of the term has steadily increased each year, so a trend in this direction may be inferred.

3.4 Contextual Analysis

To understand how the keywords were used in the literature, we continued with a contextual analysis of the corpus, running concordance and collocation analyses. While somewhat different in the way they are carried out, they both served the purpose of contextualizing vocabulary in literature by revealing associated words and topics.

3.4.1 Concordance

A concordance is a tool used in lexicographic analysis that returns a list of words that appear directly before or after a given term in a corpus. By itself, a concordance doesn't feature sorting or filtering methods, so for our use, we performed our own ranking and qualitative categorization to on the results to characterize the results.

To start, the papers making up our corpus were converted from .pdf to plain text files using the free PDF2Text Pilot application [5]. Then they were processed with CasualConc [6], a linguistic analysis tool, which showed each keyword occurrence in its original context. Manual filtering of the surrounding text yielded a list of associated terms, which were then sorted into five categories: System quality attributes (including the original search terms), design terms, usage terms, functional and descriptive terms, and specific areas of focus. This provided an indication of some specific contexts in which DMI system quality issues have been addressed in research. The most frequent terms related to our keywords (and including the keywords themselves), sorted by category, can be seen in Table 4.

3.4.2 Collocation

Along with the concordance analysis, we performed a collocation on the corpus, which ranks the positional relationship of related words and phrases to the original terms [19]. While the terms revealed from the concordance results were filtered manually and involved a certain amount of subjective judgment, the collocation was a strict quantitative analysis that yielded a ranked list of words appearing directly to the left and right of the keywords in the texts. A stop list was used to filter out common words that that are not relevant to our topic [20], and the results were compiled into a list of terms for each keyword. The top results across all keywords are displayed as a word cloud in Figure 5.

3.4.3 Grouped Results

To bring the results together, the terms produced from both analyses were grouped together thematically, then compared and reduced to yield fifteen terms, shown in Table 5. Collectively, these terms comprise a focused set of related issues from the literature that pertain to the design of highly functional DMIs intended for active use in performance.

More work remains to provide a detailed accounting of how these key design areas can be effectively addressed in

[5] http://colorpilot.com/extract-pdf-text.html

[6] https://sites.google.com/site/casualconc/Home

Figure 5. Related terms from collocation analysis.

Physical design	Technology	Build quality
Feature set	Compatibility	Control
Functionality	Usability	Sustainability
Musicality	Timing & latency	Product support
Feedback	Communication	Versatility

Table 5. Key design areas for DMI performance

the creation of functional, performance-ready instruments. For one, the areas arise across different levels of the design process, from low-level engineering concerns such as choice of technologies and communication protocols, to high-level issues of musicality, usability and versatility. Continued research will seek to develop the initial findings presented here into specific design recommendations.

4. CONCLUSIONS AND FUTURE WORK

In this paper we examined some of the core issues around the design of functional DMIs intended for professional, long-term use. We presented findings from a user survey by the first author, along with data from a related survey, which indicate that many new instruments see limited use in actual performance. While this is partially due to the fact that instrument designers do not always intend for their instruments to be used in performance, overall both surveys showed that basic functional issues related to instrument stability, reliability and compatibility are common factors that limit their suitability for regular, long-term use and increase their likelihood of being abandoned.

We have provided an analysis of published literature spanning forty years of DMI development and performance to conceptualize how and where these areas have been addressed previously. Our review of more than 2000 papers from the ICMC, NIME and SMC conferences shows that despite a historical lack of focused attention, increasing consideration has been paid to these issues in recent years. From our results, we have identified a set of key design areas that could be addressed to facilitate the creation of robust, reliable instruments ready for regular use in performance.

The literature analysis allowed us to quickly gain a high-level understanding of trends from a large document set. Our continued work will entail returning to the collected documents to extract more detailed information around these topics and compile a thorough review of the topics presented here. In addition to this work, we intend concentrate our grounded efforts on the practitioners: designers and performers. A new survey is under way to gather more focused information about musicians working with DMIs, and a user study has been planned to track a small group of musicians using a new DMI prototype over an extended period of time.

In considering the general topic of fostering more widespread and sustained use of DMIs in performance, we note that DMIs are often idiosyncratic in their design [21] and are not widely used in mainstream professional performance contexts. While a professional musician might not be the prototypical target for most DMI creations, designing for this type of active user can be beneficial. An important part of NIME research is dedicated to performance with DMIs, and the community benefits most when DMIs are put into use [16]. By considering active, professional musicians who have to depend on the tools they use, we hope to highlight these design considerations that can lead to the creation of robust, reliable instruments ready for their moment in the spotlight.

5. REFERENCES

[1] M. M. Wanderley and M. Battier, Eds., *Trends in Gestural Control of Music*. Paris, France: IRCAM - Centre Georges Pompidou, 2000.

[2] S. Jordà, "Digital instruments and players: part I—efficiency and apprenticeship," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Hamamatsu, 2004, pp. 59–63.

[3] C. Mamedes, M. Rodrigues, M. Wanderley, J. Manzolli, D. H. L. Garcia, and P. Ferreira-Lopes, "Composing for DMIs - Entoa, a Dedicate Piece for Intonaspacio," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, London, 2014, pp. 509–512.

[4] F. Morreale and A. McPherson, "Design for Longevity: Ongoing Use of Instruments from NIME 2010-14," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Copenhagen, 2017, pp. 192–197.

[5] F. Morreale, A. D. Angeli, and S. O'Modhrain, "Musical interface design: An experience-oriented framework," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, London, 2014, pp. 467–472.

[6] P. R. Cook, "Principles for Designing Computer Music Controllers," in *Proceedings of the International*

Conference on New Interfaces for Musical Expression, Seattle, 2001, pp. 3–6.

[7] ——, "Re-Designing Principles for Computer Music Controllers : a Case Study of SqueezeVox Maggie," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Pittsburgh, 2009, pp. 218–221.

[8] E. R. Miranda and M. Wanderley, *New Digital Musical Instruments: Control and Interaction Beyond The Keyboard*. A-R Editions, 2006.

[9] B. Buxton, "Artists and the art of the luthier," *ACM SIGGRAPH Computer Graphics*, vol. 31, no. 1, pp. 10–11, 1997.

[10] A. R. Jensenius and M. J. Lyons, "Trends at NIME: Reflections on Editing A NIME Reader," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Brisbane, 2016, pp. 439–443.

[11] C. B. Medeiros and M. Wanderley, "A comprehensive review of sensors and instrumentation methods in devices for musical expression." *Sensors (Basel, Switzerland)*, vol. 14, no. 8, pp. 13 556–91, 2014.

[12] M. M. Wanderley, "Expert Commentary: Perry Cook's Principles Still Going Strong," in *A NIME Reader: Fifteen Years of New Interfaces for Musical Expression*, A. R. Jensenius and M. J. Lyons, Eds. Springer, 2017, pp. 11–13.

[13] J. Sullivan, "Interaction and the Art of User-Centered Digital Musical Instrument Design," Master's thesis, University of Maine, Orono, ME, USA, 2015.

[14] F. Morreale, A. P. Mcpherson, and M. M. Wanderley, "NIME Identity from the Performer' s Perspective," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Blacksburg, 2018.

[15] S. Ferguson and M. Wanderley, "The McGill Digital Orchestra: An Interdisciplinary Project on Digital Musical Instruments," *Journal of Interdisciplinary Music Studies*, vol. 4, no. 2, pp. 17–35, 2010.

[16] C. Dobrian and D. Koppelman, "The 'E' in NIME: Musical Expression with New Computer Interfaces," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Paris, 2006, pp. 277–282.

[17] A. R. Jensenius, "To Gesture or Not? An Analysis of Terminology in NIME Proceedings 2001–2013," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, London, 2014, pp. 217–220.

[18] I. Poupyrev, M. J. Lyons, S. Fels, and T. Blaine Bean, "New Interfaces for Musical Expression," *ACM Conference on Human Factors in Computing Systems (CHI)*, p. 491, 2001.

[19] D. Biber, "Co-occurrence Patterns Among Collocations: A Tool for Corpus-based Lexical Knowledge Acquisition," *Comput. Linguist.*, vol. 19, no. 3, pp. 531–538, 1993.

[20] A. Rajaraman and J. D. Ullman, "Data Mining," *Mining of Massive Datasets*, pp. 114–142, 2011.

[21] M. Wanderley and N. Orio, "Evaluation of Input Devices for Musical Expression: Borrowing Tools from HCI," *Computer Music Journal*, vol. 26, no. 3, pp. 62–76, 2002.