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An App-Based Authoring System for Personalized Sensory Stimulation of Children With Developmental Disabilities

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ABSTRACT Children with developmental disabilities typically have sensory processing disorders, which may result in considerable discomfort. Sensory stimulation therapy is the most common remedy, but the development of therapy content is challenging because each individual has unique sensory problems and personal characteristics. To provide personalized content, we propose a new app-based authoring system, in which various functionalities provided by different apps can be dynamically combined and reconfigured. Specifically, we develop: 1) an authoring app, which allows authors to reconfigure the functionality of different apps using parameters; 2) an execution app, which dynamically runs various components in different apps; and 3) app packages to stimulate sensory systems, for which a library is provided to support effective app development on our platform. To stimulate the multi-sensory systems of children with developmental disabilities, several items of content were developed with guidance from special education teachers. User studies reveal that the proposed scheme is effective for the development of personalized educational content, thus helping sensory stimulation therapy.

INDEX TERMS Multimedia systems, authoring systems, mobile computing.

I. INTRODUCTION

The phrase developmental disability describes a diverse group of chronic conditions that result in mental or physical impairments. Children with developmental disabilities often experience problems with major life activities such as communication, mobility, self-help, and independent living [1]. It has recently been reported [2] that approximately 1 in 6 children in the US have one or more developmental disabilities, and that the number of such children has increased by 17.1% in the past 12 years.

Children with developmental disabilities typically have sensory processing disorders [3], [4], making them abnormally sensitive or insensitive to stimuli; for example, they can react strongly to sounds with particular frequencies, to certain colors, or even to some types of fabric. These reactions can take the form of unexpected movements or protective behavior, and in autistic children, who have difficulty relating to others, this may be regarded as willful misbehavior. Alternatively, a child with a sensory processing disorder may fail to react adequately to extreme heat or cold, thus putting themselves in danger.

Therapies for sensory disorders typically focus on teaching children how to integrate their senses, become more aware of their bodies, and adapt better to their environment. Examples of such therapies include activities that stimulate the sensory system by providing input related to body position, touch, balance, and hearing [5], [6]. Brushes, swings, balls, and other specially designed therapeutic or recreational equipment are used to provide these inputs [7]. Devices like these may also be integrated into a multi-sensory environment in a specialized room, allowing for controlled sensory stimulation [8]; however, access to such environments is limited by cost.

An alternative approach has become available thanks to the growth of mobile technology and the wide availability of smartphones. For example, many educational apps are now available in smartphones or tablet PCs, some of which allow teachers to develop their own educational content [9], and some of which are suitable for children with developmental disabilities. For example, an app has been developed to improve speech in children with autism by presenting pictures to them [10].

Many smartphones now have built-in sensors, and the growth of wearable technologies has also led to the development of wearable sensors; these in turn have led to the development of apps for sensory stimulation. To optimize these technologies, it is desirable to combine diverse functionalities from a number of apps; for example, video content might be combined with vibration generation. However, the current generation of apps run independently, and cannot be combined.

Children with developmental disabilities are more diverse than others in terms of learning styles and interests, sociability, abilities, and disabilities. For example, some children respond only to their parents' voices, and it is important to accommodate these personal characteristics when developing educational content. This suggests that apps for children with developmental disabilities should have the following properties: (1) functionality that can easily be added or updated; (2) functionality that can be combined with that of other apps; (3) the facility to configure a sequence of app executions dynamically; and (4) the facility to configure content parameters dynamically.

We propose a new approach to app-based authoring, in which personalized development of content is facilitated through collective use of the functionalities provided by different apps. We first present an authoring architecture in which content developed on authoring devices is delivered to the target device on which it runs. We have also developed: (1) a programming library to support the development of app functionalities that will be included in the content; (2) an authoring app that allows content that dynamically combines the functionalities of different apps, to be created and executed; (3) an execution app that allows children to run the authored content. To assess the proposed scheme, content developed under the guidance of special education teachers to provide multi-sensory stimulation, has been used in a summer camp for children with developmental disabilities. User studies were conducted to evaluate its usefulness.

The rest of this paper is organized as follows: Section II reviews related work, and Section III presents the design of our system. Section IV provides details of the system implementation, and Section V describes the content development process. Finally, Section VI presents experimental results, and Section VII concludes the paper.

II. RELATED WORK

A. AUTHORING SYSTEMS

An authoring system provides an interface that allows the specification of spatial and temporal relationships among objects that compose multimedia content [11]. For example, structure-based schemes represent the relationship between media objects in the form of a storyboard, timeline-based schemes order the objects over time, graph-based schemes build them into a directed graph, and script-based schemes embed them in text [11].

Several techniques have been developed to support a wide range of multimedia authoring and presentation requirements. For example, to capture various multimedia objects in a presentation quickly, Müller and Ottmann [12] developed a system that allows automatic recording and replay of multimedia presentations. Chiueh *et al.* [13] developed an interactive authoring system called Zodiac, which facilitates the authoring process based on editing history. Borning *et al.* [14] developed a framework for authoring a Web document, which allows authors and viewers to specify constraints for multimedia documents on specific websites, so that a final layout can be negotiated. Scherp and Boll [15] developed a context-aware smart multimedia authoring tool called xSMART to reflect user context in the authoring steps. They developed a wizard-based interface that analyzes authors' domain-specific requirements to create content targeted to a specific user context.

Several systems have been developed specifically for organizing video-based content. Ma *et al.* [16] developed a sketch-based video authoring system. Based on the analysis of authors' sketches, it infers their intent and executes appropriate operations such as searching for similar sketches, recommending related video clips, and manipulating video data, to provide an interactive authoring environment. Liu *et al.* [17] proposed an authoring system that organizes video content based on authors' sketch annotations. It recommends related sketch annotations in the database based on the authors' simple drawings. Liu *et al.* [18] developed a video authoring tool called SpiralTape, which summarizes video content in a smooth spiral pattern by preprocessing video clips into hierarchical structures, and extracting regions-of-interest from the keyframes. They pointed out that this tool is especially useful for stimulating environments such as science and technology museums, allowing children to have more enjoyable experiences.

Some authoring systems run on mobile devices. For example, Abu-Naim and Klas [9] presented an authoring architecture for effective sharing of content in mobile devices across a personal area network. This automatically analyzes the multimedia content on the devices, to compose multimedia documents that match users' subjects of interest. Teng *et al.* [19] developed a diary-like authoring system, in which content is integrated with geographic information and can be edited as a storyboard. In these systems, the three techniques used to facilitate mobile authoring are storage-constrained uploading, sensor-assisted editing and map-based content management. Jokela *et al.* [20] developed a presentation editor to compose multimedia stories on mobile devices, focusing mainly on the development of an authoring interface for sophisticated multimedia presentations on small mobile devices.

The components of most authoring systems are not reusable, and it can also be difficult to reuse content with different formats. To address this, Santanchè *et al.* [21] developed an authoring system in which content is wrapped in components, which can then be used to generate further content. However, this is a web-based system, whereas app-based systems are more appropriate for mobile systems.

Nevertheless, authoring issues specific to mobile devices have been tackled in several recent papers. For example, uploading facilities have been introduced [19] to overcome the limited storage on mobile devices, whilst content sharing across personal area networks is an effective content distribution method [9]. GPS and other sensor output can also be integrated into authoring systems [15]. To the best of our knowledge, however, there is currently no system which allows components in different apps to be combined.

B. SYSTEMS FOR SENSORY STIMULATION OF CHILDREN WITH DEVELOPMENTAL DISABILITIES

Several systems with multimodal user interfaces have been developed for children with developmental difficulties. Piper *et al.* [22] developed a system for language-learning called Tap & Play, in which recorded audio clips are played when a child writes on specified regions of a sheet of paper using a digital pen. Jordà [23] and Villafuerte *et al.* [24] have described systems for music-based therapy, in which music is played when children place their hands on specific regions of a tabletop surface. Chung *et al.* [25] developed a hand-worn device called OnObject with an RFID reader and a tri-axis accelerometer, which can recognize both gestures and tagged objects, and allows children to relate them to speech clips. Cibrian *et al.* [26]–[28] developed a fabric-based musical surface called BendableSound, which improves cognition in young children by allowing them to play piano-like sounds. Farr *et al.* [29] used a construction toy called Topobo, which can play back motions to improve social interaction in children with autism.

Multisensory environments (MSEs) are rooms or spaces containing equipment designed to provide sensory stimulation to children with developmental disabilities [8]. Ringland *et al.* [3] proposed a multimodal environment that allows children to use physical objects and body-based interactions on a large display; the display provides tangible interactions and interactive audio feedback, with the aim of promoting socialization. Tentori *et al.* [30] describe an interactive physical world furnished with sensors, actuators, and novel displays. Sharma *et al.* [31] presented a gesture-based interactive environment to improve social, motor and cognitive skills. Chen *et al.* [32] used augmented reality technology to make a storybook with video clips that matched facial expressions with emotions for specific social situations, with the aim of teaching sociality. All of this work focused primarily on the development of multimodal environments to stimulate sensory systems; it took no account of content authoring, which is essential for personalized therapy.

III. DESIGN

A. BASIC CONCEPT

We have developed an authoring system with the aim of (1) combining various functionalities from different apps; (2) specifying the sequence of app executions; and (3) configuring parameters dynamically. An authoring app is provided to authors to develop their content, while an execution app is provided to users for content execution. An activity, which is a program unit that can be displayed on a screen with which users can interact [33], is used as a basis for content composition. Authors can compose content by combining various activities from the package of content apps.

To provide personalized content composition while enriching content, the following features are incorporated into the authoring system:

1) To make use of different functionalities developed by many app developers for a single item of content, a server is maintained on which app developers can register their app information; this may include, for example, the UI configuration method for the authoring app. This registration allows authors to use different UI interfaces, optimized for each function within different apps. For example, in a YouTube app, a video source URL address can be configured, whilst in a quiz app the number of questions or degree of difficulty can be defined by the author.
2) Authors make use of an authoring app to receive a list of registered apps from the server, and to develop content by reconfiguring various functionalities of the different apps. Two editing modes (flow-chart and list-based interfaces) are provided for content composition.
3) An execution app is used to execute the activities of different apps. An intent mechanism allows the execution app to invoke activities in the different apps by binding activities at run-time [33]. Different activities from different apps can be combined using this intent mechanism.

B. ARCHITECTURE

Fig. 1 shows the architecture of the entire system, composed of authoring devices, a management server and target devices. Authors can develop content using an authoring app on their authoring devices, whilst the content is executed by the execution app running on the target devices.

The server stores the list of apps and their activities installed on each target device, allowing management of the interaction between the authoring and target devices. For this purpose, it keeps a list of activities and their features for each content app; these lists can be delivered to the authoring app on request.

C. PROTOCOL

The entire authoring and execution process in Fig. 1 can be described as follows:

1) Content app registration: Each content app developer registers the list of activities on the management server,

TABLE 1. Registration format of each content app.

Field	Description	Mandatory or optional
	1. App information part	
Description	Explanation of app features	Mandatory
	2. Activity information part (per each activity)	
Activity name	Name of the activity	Mandatory
Description	Activity explanation	Mandatory
Reference site	A URL address that helps understand activity	Optional
UI type	UI format used for parameter setting in an authoring app (e.g. Multiple-choice (checkbox or radio button) and direct input)	Mandatory if parameters are used
File option	Parameters can be configured using files (true or false)	Optional
Number of parameters	Number of parameters	Mandatory if parameters are used
Parameter 1	Parameter explanation	Mandatory if parameters are used
...	...	Mandatory if parameters are used
Last Parameter	Parameter explanation	Mandatory if parameters are used
Author-defined parameters	Number of configurations required to define parameters	Optional
Author-defined parameter 1	Parameter explanation	Optional
...	...	Optional
Last author-defined parameter	Parameter explanation	Optional
	3. Branch condition part (per each activity)	
Description	Explanation of branch condition	Mandatory if branch is used
UI type	UI format used for condition setting	Mandatory if branch is used
Condition	Explanation of result condition for true setting	Mandatory if branch is used

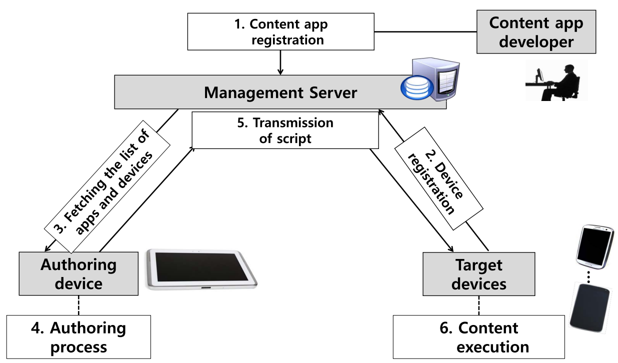

FIGURE 1. Authoring system architecture and process.

in the form of a file. This process is only required when the apps are installed or changed.

2) Device registration: The execution app on each target device registers on the server by sending the list of available apps installed on the target device.
3) Fetching the list of apps and devices: The authoring app receives a list of available target devices and apps from the server, which allows authors to develop personalized content for each target device.
4) Authoring process: Authors can compose content using their authoring app.
5) Transmission of script: After the authoring process, the content is converted into a script and can be delivered to the execution app on the specified target devices.
6) Content execution: An execution app runs the script as specified by the authors.

To provide authors with the list of apps and activities that can be configured and parameterized, the authoring app fetches a list of content app characteristics. Table 1 shows the format in which each content app developer can register app characteristics. Mandatory fields must be provided, whereas optional fields are configured only if necessary. This format can be divided into three parts, as follows:

1) App information part: This part describes the characteristics of apps, such as the app name and its functionality.
2) Activity information part: This part explains the details of the activities, as follows:
   - The activity name and description must be provided. A website address can be added to explain the details of this activity.
   - If necessary, the parameters of each activity can be specified using three different UI types: checkbox, radio button and direct input. Authors can select two or more parameters in the checkbox type, but only one parameter can be chosen in the radio button type. The direct input type allows authors to specify the parameters. Different types can be also combined; for example, checkbox and direct input types can be used together.
   - Authors are also allowed to add additional parameters using the direct input type, but this functionality can also be ignored.
3) Branch condition part: This part allows authors to execute one of two activities, depending on the result of the activity execution. A condition that determines either the left or right activity in the flow-chart can also be configured by authors.

Fig. 2 shows an example of the user interface in an authoring app, in which a rectangle, a rhombus and a rounded rectangle represent the activity execution, a conditional symbol, and the start or end of the content, respectively. When these

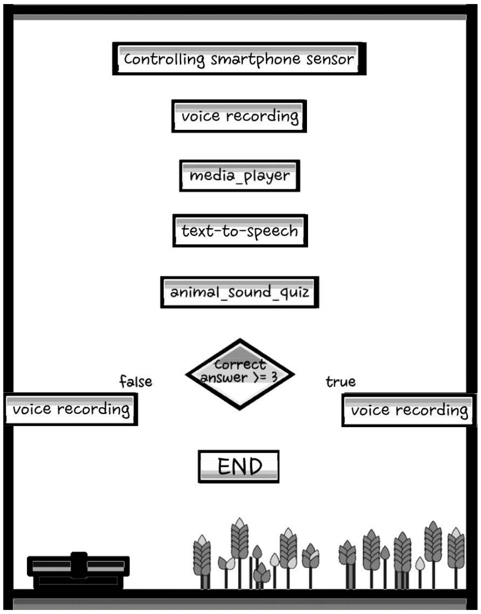

FIGURE 2. Example of flow-chart in authoring app.

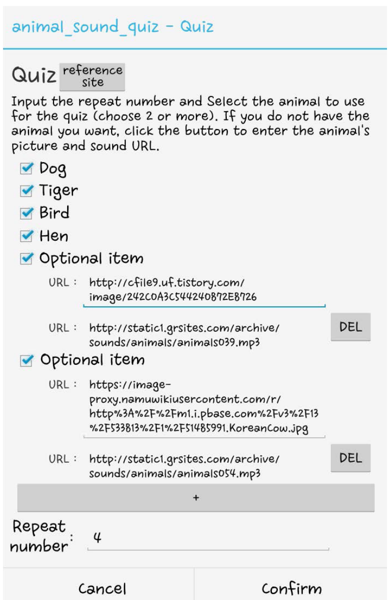

FIGURE 3. Example of user interface for parameter configuration.

symbols are selected, authors can select the activity for the parameter configuration. For example, when the rectangle for an animal sound quiz is pressed in Fig. 2, a new display is launched to allow authors to configure parameters, as shown in Fig. 3. The example in Fig. 2 is composed of five activities: (1) a sensor control activity that attracts users using a flashing light, vibration, or alarm; (2) a voice recording activity that records authors' voices, which are played to users; (3) a media player activity that plays video clips from either YouTube or local storage; (4) a text-to-speech (TTS) activity which converts text to voice; and (5) an animal sound quiz activity, which asks several questions to match animal sounds with pictures.

IV. IMPLEMENTATION

A. BASIC SOFTWARE ARCHITECTURE

Each content is an array list of the app class data structures. The construction of this array is completed when the content parameters are configured by the authoring app; this is then delivered to the execution app, which runs the activities as configured in the array. For example, Fig. 4 shows an array of classes constructed for content in Fig. 2, with each class comprising three items: (1) an app item for app information (ExecutionItem in Fig. 4); (2) an activity item for activity information (SelectedComponent in Fig. 4); and (3) parameter items, which include the parameters specified by authors.

B. PROGRAMMING LIBRARY

We have developed a programming library to allow content app programmers to write app programs efficiently. The library APIs can be divided into four categories depending on their usage, as follows:

1) APIs related to the app item: App item information such as the name, array list of activities, and number of activities, can be retrieved using these APIs.
2) APIs related to the activity item: Activity item information such as the activity name and number of parameters in the activity, can be checked using these APIs.
3) APIs related to the parameter items: These APIs can be used to retrieve parameters configured by the authors.
4) APIs related to the branch statement: The results of the activity execution can be retrieved by using these APIs in the branch condition part.

C. AUTHORING APP

The authoring app receives the list of target devices from the server, and chooses the target devices to which the content will be delivered. After checking the list of content apps in the target device, authors can compose the content using the interface in Fig. 2, as follows:

1) Flow-chart construction: Authors can construct a flow-chart of activities as shown in Fig. 2.
2) Content transmission: When the authoring process finishes, authors send the content to the target devices, allowing an execution app to run the content.

D. EXECUTION APP

An execution app receives the content from the authoring app, and utilizes an intent mechanism to run the content as specified by the author. It executes the content app as enumerated in the array of app items, and delivers this app item class to the content app; this then checks the authors' parameters by looking at the parameter values in the class. Our system also allows apps available in app markets to be used for content composition, but it is not possible to configure their

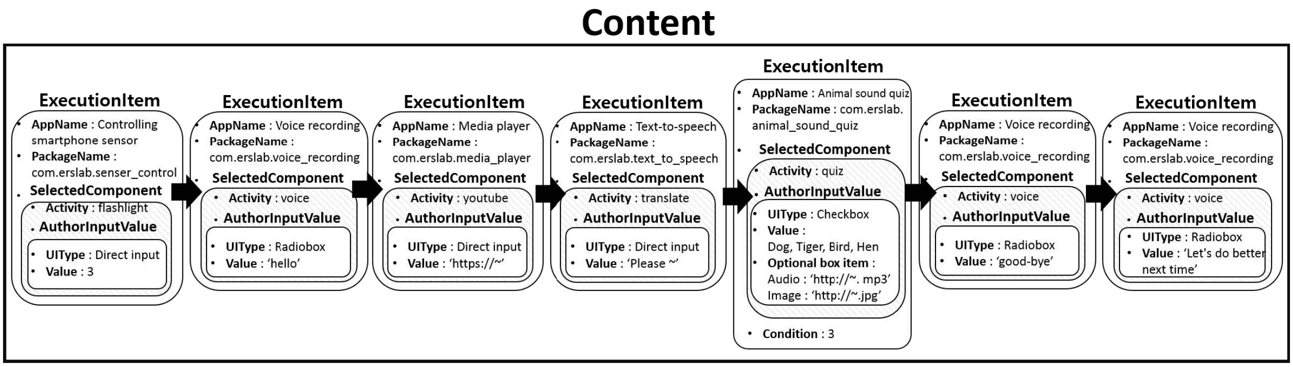

FIGURE 4. Example of an array list constructed during the authoring process.

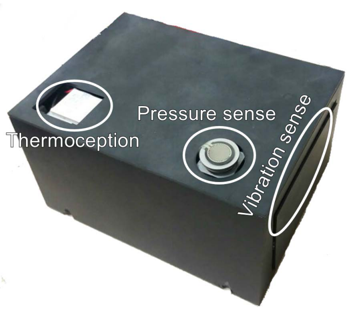

FIGURE 5. A haptic device.

FIGURE 6. Example of content execution using a haptic device.

parameters since this requires modification to the app source code.

V. CONTENT COMPOSITION

A. HARDWARE ENVIRONMENT

A haptic device in Fig. 5 was used to stimulate the sensory systems of those with developmental disabilities. Fig. 6 shows an example of content execution by a child diagnosed with developmental disabilities, using this device. The details of the hardware components can be summarized as follows:

1) Thermoception: To generate a thermoelectic effect, a Peltier module is used with a temperature sensor. The temperature range is between 18 and 37 degrees Celsius.
2) Vibration: Four vibration motors are used to generate the intensities and directions of vibration. The directions of vibration are from top to bottom, bottom to top, left to right, and right to left. The intensity can be expressed on a five-scale range, from "very slow" to "very fast".
3) Pressure: A magnetorheological fluid is used to generate 3 levels of firmness.

B. CONTENT COMPOSITION

Seven apps were developed to stimulate sensory systems of those with developmental disabilities, as described in Table 2. With the guidance of special educational needs (SEN) teachers, we composed five items of content, as follows:

1) Coldness perception: This content was developed to teach coldness perception by association with the concept of snow. A short video clip named "Frozen" is played using YouTube, and a child is then guided by the carer's voice to touch the haptic device, which is set to 18 degree Celsius.
2) Hotness perception: This content was developed to teach hotness perception, by association with the concept of fire. A short video clip named "Be careful with fire" is played using YouTube, and a child is then guided by the carer's voice to touch the haptic device, which is set to 37 degree Celsius.
3) Vibration perception: This content was developed to teach vibration perception. A short video clip named "Let's go around" is played using YouTube, and a child is then guided to touch the haptic device, which is set to vibrate from left to right.
4) Firmness perception: This content was developed to teach firmness concept by associating it with a golden ring. A short video clip about the ring is played, and a child is then guided to touch the pressure sensor.
5) Animal sound recognition: This content was developed to match an animal cry with a picture of the animal. A video clip named "Animal farm" is played, and a child is then guided to solve the animal sound quiz. Branch functionality is used to praise the child when

TABLE 2. List of apps used for content composition.

App name	Number of activities	Activity description	UI type	Parameters	Branch condition	Relevant sensory system
Animal sound quiz	2	Matching animal sounds with pictures	Checkbox	Animal name, image, sound file path	Number of Correct answers	Vision Auditory sense
			Direct input	Number of questions		
		Matching animal sounds with pictures at specific homepages	Checkbox	Animal name, image or URL		
			Direct input	Number of questions		
Haptic device control	4	Temperature setting	Radio button	Temperature	None	Tactile sense
		Firmness setting	Radio button	Degree of firmness		
		Vibration intensity setting	Radio button	Vibration intensity		
		Vibration direction setting	Radio button	Vibration direction		
Gesture recognition	2	Counting number of shaking	Direct input	Number of shakings	None	None
		Detection of swiping direction	Direct input	Direction		
Playing a recorded voice file	2	Playing a voice memo	Radio button	Voice types	None	Auditory sense
		Playing a voice memo with an image	Radio button	Voice types		
			Direct input	Image file name		Vision
Media player	2	Playing a YouTube video	Direct input	YouTube URL for play	Playback time	Vision Auditory sense
		Playing a video file	Direct input (File option)	Video file name		
Controlling smartphone sensors	3	Turning on flashlight	Direct input	Duration of flashlight	None	Vision
		Controlling vibration on smartphones	Direct input	Duration of vibration		Tactile sense
		Playing an alarm sound	Direct input	Duration of alarm sound		Auditory sense
TTS	1	Translation from text to speech	Direct input	Text to be converted to speech	None	Auditory sense

the correct number of answers exceeds 3. Fig. 2 shows its user interface in the authoring app.

VI. EXPERIMENTAL RESULTS

A. EXPERIMENTAL SETUP

A user study was conducted by SEN teachers to examine the efficacy of the proposed authoring system, as follows:

1) Usefulness of app combination: To examine the usefulness of the app combination for sensory stimulation, a single app was compared with content composed using multiple apps.
2) Usefulness of authoring features: The efficacy of authoring features such as branch, input parameter settings and reusability of apps was examined.
3) Usability of the authoring app: User experiences of the authoring app were verified.

Two survey methods were used: online web-based, and offline paper-based. For the online survey, we provided each participant with web links to questionnaires using a Google survey form. For the offline survey, a paper-based questionnaire was given to each participant. The online survey was performed to evaluate the usefulness of the app combination and authoring features, whilst the offline survey was used to test the user experience of the authoring app. A total of 52 SEN teachers participated in the online survey; among these, 11 teachers completed the off-line survey. Fig. 7 and Fig. 8 show the demographics (i.e., age, gender and educational experience) of the SEN teachers for the online survey and offline surveys, respectively.

For a preliminary survey, three questions were developed to understand the motivation for our system, as shown in 3. We used the multiple-choice 5-point Likert scale form for answers, as follows: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. Fig. 9 shows the results, and the following observations were made from this survey:

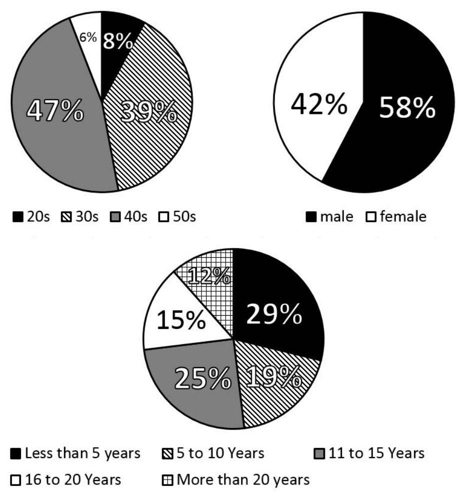

FIGURE 7. Demographics of the 52 teachers completing the online survey.

1) 82.69% (43 out of 52) of the respondents had actively looked for educational content for those with developmental disabilities (MD: 4.13, SD: 0.69).
2) 94.23% (49 out of 52) of the respondents think that educational content on existing app markets is unsatisfactory (MD: 4.37, SD: 0.57).
3) 98.08% (51 out of 52) of the respondents think that personalized content is important for sensory stimulation of those with developmental disabilities (MD: 4.59, SD: 0.50).

B. SURVEY RESULTS: USEFULNESS OF APP COMBINATION

We compared content in a single app (single-app content) with content from multiple apps (multi-app content). Each participant watched a video clip with single-app and multi-app contents. For the single-app content, either a haptic device control app or an animal sound quiz app was executed. For the multi-app content, five items of content from

TABLE 3. Questions about motivation for personalized education.

Q1. I have actively looked for educational content for those with developmental disabilities.
Q2. Educational contents on app markets are unsatisfactory for personalized education of those with developmental disabilities.
Q3. Each child requires personalized content for sensory stimulation.

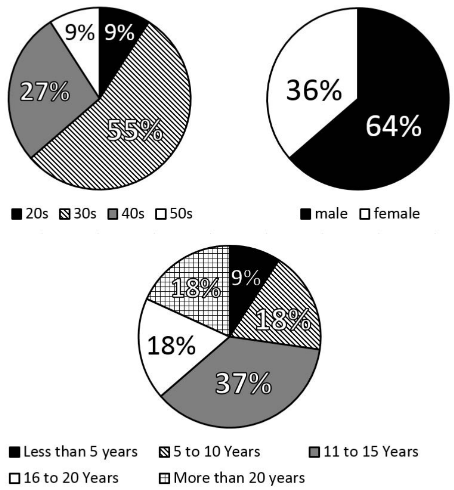

FIGURE 8. Demographics of the 11 teachers completing the offline survey.

TABLE 4. Questions relating to single-app and multi-app content.

Q1. Which of the following is more effective for learning about coldness perception?
Q2. Which of the following is more effective for learning about hotness perception?
Q3. Which of the following is more effective for learning about vibration perception?
Q4. Which of the following is more effective for learning about firmness perception?
Q5. Which of the following is more effective for learning about animal sounds?

multiple apps were executed as described in Section V. Each participant was instructed to choose either single-app or multi-app in response to the questions in Table 4. Forty one participants answered these questions. As expected, between 87.8% and 97.44% of the respondents answered that multi-app content is more effective than single-app content.

To examine the efficacy of activity combinations in different apps as shown in Table 2, we developed the questions in Table 5 using multiple-choice answers on the 5-point Likert scale. Fig. 10 shows the results from which the following observations can be drawn:

1) Q1: 97.56% of the respondents (40 out of 41) agreed that multi-app content is effective for sensory stimulation (MD: 4.63, SD: 0.62).
2) Q2: 95.12% of the respondents (39 out of 41) agreed that multimedia data such as videos are effective for sensory stimulation (MD: 4.63, SD: 0.69).
3) Q3: 82.93% of the respondents (34 out of 41) agreed that carer's voices are useful for sensory stimulation (MD: 4.59, SD: 0.64).
4) Q4: 80.49% of the respondents (33 out of 41) agreed that the TTS app is useful for the composition of content (MD: 4.27, SD: 0.7).

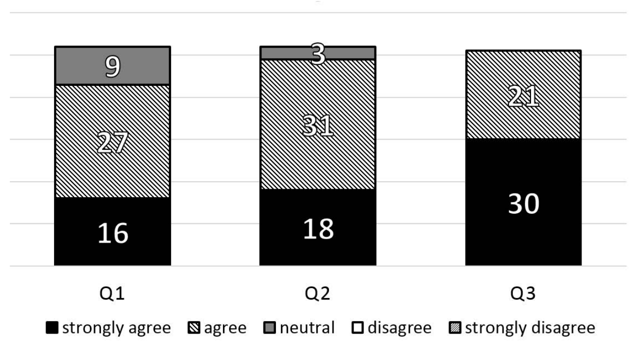

FIGURE 9. Results of preliminary survey.

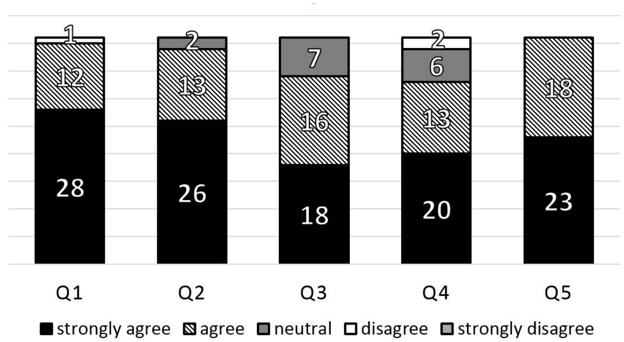

FIGURE 10. Survey results: Efficacy of content composition.

5) Q5: All the respondents agreed that assignments are useful for sensory stimulation (MD: 4.24, SD: 0.84). This implies that the branch functionality in our system is quite effective, because different activities can be executed as a result of assignment completion.

C. SURVEY ABOUT USEFULNESS OF THE AUTHORING APP

This survey was conducted to examine the usefulness of the authoring app. Each participant watched a video clip explaining how to use the authoring app, and responded to the questions in Table 6 using a 5-point Likert scale answer form. Fig. 11 shows the survey results, from which the following results can be extrapolated:

1) Q1: 63.46% of the respondents (33 out of 52) agreed that content can be easily developed without professional knowledge (MD: 3.60, SD: 0.69).
2) Q2: 80.77% of the respondents (42 out of 52) agreed to the usefulness of branching functionality (MD: 4.05, SD: 0.57).
3) Q3: 84.62% of respondents (44 out of 52) agreed to the usefulness of reusable functionality (MD: 4.02, SD: 0.49).

TABLE 5. Survey questions regarding efficacy of various functionalities in different apps.

Q1. For sensory stimulation, multi-app content is more effective than using a haptic device only.
Q2. Multimedia data are effective for sensory stimulation.
Q3. The carer's voice is effective for sensory stimulation.
Q4. The TTS app is effective for the development of sensory stimulation content.
Q5. Assignments in the content (e.g. matching animal sounds with images or swiping the screen in a given direction) are effective for sensory stimulation.

TABLE 6. Survey questions regarding the usefulness of the authoring app.

Q1. It is easy to create content without professional knowledge.
Q2. Branch functionality is useful.
Q3. Reusing existing content items such as video, image, sound, and apps is useful.
Q4. Parameter-setting functionality is useful.
Q5. I am willing to use this authoring app.

TABLE 7. Survey questions regarding usability of the authoring app.

Q1. It is easy to organize activities in different apps.
Q2. It is easy to make use of branch functionality.
Q3. It is easy to configure parameters.
Q4. It is easy to save and load content.
Q5. It is easy to embed available apps on the smartphone (not content apps) into the content.
Q6. It is easy to modify previous parameters.
Q7. It is easy to transfer files between authoring and target devices.
Q8. It is useful to make use of URL such as YouTube for enriching content.
Q9. It is easy to redo content.
Q10. Content items are executed as intended by the authors.

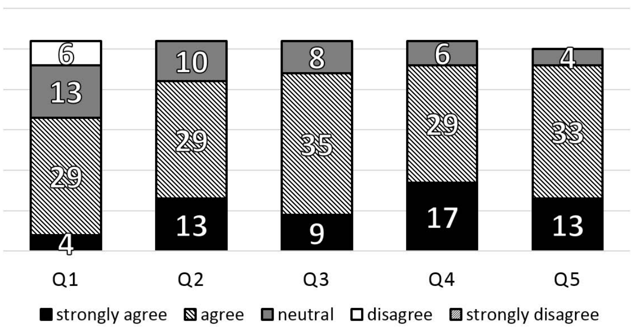

FIGURE 11. Survey results: Usefulness of the authoring app.

4) Q4: 88.46% of respondents (46 out of 52) agreed to the usefulness of parameter setting functionality (MD: 4.21, SD: 0.80).
5) Q5: 88.46% of respondents (46 of 52) stated that they would use this authoring app (MD: 4.18, SD: 0.67).

D. SURVEY ABOUT USABILITY OF THE AUTHORING APP

Eleven teachers participated in the authoring app usability test. An LG G Pad 2 was used for the authoring experience, and a Samsung Galaxy J5 used for running the content. The experiment was conducted at a Dong-chun school, an educational institution for children with developmental disabilities, located in Seoul, Korea. Eleven apps were used for the user experience. These comprised the seven apps shown in Table 2, and the additional four content apps: A voice recognition app, a color matching app, a speech-to-text (STT) app, and a question-and-answer app, which allows authors to develop questions. Fig. 11 shows survey results to the questions in Table 7. All the participants gave scores of 3, 4 or 5 to each question, indicating that no negative opinions were expressed for usability. Notably, the highest score was given by 51% of the respondents on average.

E. A CASE STUDY FOR CHILDREN WITH DEVELOPMENTAL DISABILITIES

We tested our system at a summer camp for young people diagnosed with developmental disabilities. A total of 112 children participated in content execution for two days. Our observations can be summarized as follows:

1) Coldness perception: Most of the children said that *"It's cold"* or *"Cool"*, indicating that they clearly felt a temperature drop. It seemed that they probably liked this content the most because they were familiar with the clip "Frozen" For example, many children shouted *"Elsa"*, *"She is Elsa"* or *"I have watched this video very often with my family."* when the content started. A few children imitated Elsa's gestures.
2) Hotness perception: Most of the children seemed to feel a rise in temperature by saying *"Hot"*, *"Warm"*, and *"Lukewarm"*. Some of them sang in imitation of characters in the clip.
3) Vibration perception: Some children did not understand the concept of left or right at all, so they were instructed to move their hand in the direction of vibration on the screen of the gesture recognition app.
4) Firmness perception: Reactions to this content varied significantly. For example, some children were very unresponsive to the content, but a few children said *"It's wonderful."* This may be highly dependent on whether the firmness was felt by the child.

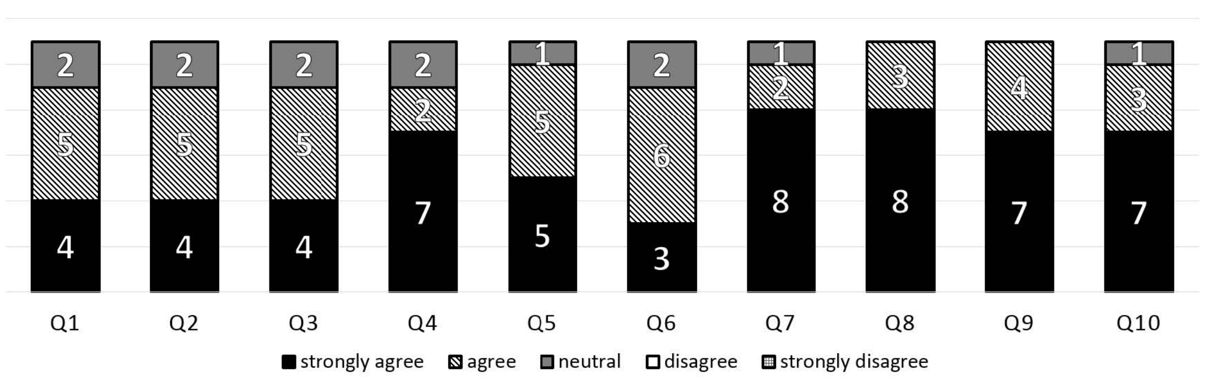

FIGURE 12. **Survey results: User experience.**

5) Animal sound recognition: Many children sang in imitation of characters in the clip "Animal farm" expressing their familiarity with this clip.

VII. CONCLUSIONS

We proposed a new app-based authoring system for the effective development of personalized content. Specifically, we have implemented: 1) an authoring app that allows authors to combine various functionalities from different apps and to configure parameters, 2) an execution app that dynamically runs various activities in different apps, 3) app packages specifically developed to stimulate the sensory systems of children with developmental disabilities, and 4) a library that supports dynamic configuration of parameters in the content.

Five content items were developed for sensory stimulation with the guidance of SEN teachers, and a case study was conducted in a summer camp to examine reactions by children diagnosed with developmental disabilities. A user study was also conducted with SEN teachers to examine the efficacy of the authoring system. The results show that: (1) personalized content is essential for sensory stimulation education; (2) multi-app content is more effective than single-app content; (3) functionalities such as parameter configuration and branching are useful for enriching content; and (4) our authoring app is easy to use.

The scalable architecture of the proposed system, whereby new functionalities in different apps can be dynamically added and reconfigured, means that it is widely applicable. We are currently enhancing the system to develop various content relevant to the elderly, and to young children.

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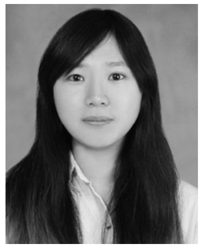

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