Static and Dynamic Haptograms to Communicate Semantic Content

Towards Enabling Face-to-Face Communication for People with Deafblindness

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***Abstract*—Based on the ontology developed in the ongoing SUITCEYES EU-funded project to bridge visual analytics for situational awareness and navigation with semantic labelling of environmental cues, we designed a set of static and dynamic haptograms to represent concepts for two-way communication between deafblind and non-deafblind users. A haptogram corresponds to a tactile symbol drawn over a touchscreen, its dynamic nature referring to the act of writing or drawing, where the touchscreen can take several forms, including a smart textile screen designated for specific areas on the body. In its current version, our haptogram set is generated over a 4 x 4 matrix of cells and is displayed on the back of the user, tested for robustness at the receiving end. The concepts and concept sequences simulating simple questions and answers represented by haptograms are focused on ontology content for now but can be scaled up.**

Keywords-deafblind communication; conceptual haptograms; word and sentence semantics; ontology.

I. INTRODUCTION

Communication with and between users with deafblindness is constrained by the medical nature of this disability, ranging from congenital to acquired deafblindness, including worsening sight or worsening hearing or both over time, plus, ultimately, symptoms of ageing as well. This renders parties with and without this condition in a difficult position. Below we focus on the severest case, congenital deafblindness, and propose a novel solution for improving the communication between user and trainer, but with the hope in mind that it can be used in the future between two such users too. In this use case, a new model of mutual understanding between the partners must be developed practically from scratch.

To this end we took inspiration from Lahtinen [1] and Lahtinen et al. [2], whose approach, while being expanded over the decades, basically reproduces ideograms on different regions of the body by a combination of hand strokes, gestures, pressure, etc. Branded as the social-haptic mode of communication, by default this is a rich tactile language with its own syntax and vocabulary of so-called *haptemes*, built from phoneme-like *haptices*, and tailored to a range of situations and topics of high practical importance including environmental descriptions, different situations, behaviour, the arts and advertisements to sum up a quick sampling. At the same time, due to its consensual nature, it is idiosyncratic and in need of being applicable in distance mode as well. This constraint makes it an ideal candidate for testing within the framework of the SUITCEYES EU-funded project [3], which is aimed at improving the quality of life for people with deafblindness through intelligent haptic technologies [4].

Another important parallel is McDaniel's PhD thesis [5], where he describes a different approach. As in a situation of sensory overload, touch is a promising candidate for messaging given that it is our largest sensory organ with impressive spatial and temporal acuity, there is need for a theory that addresses the design of touch-based building blocks for expandable, efficient, rich and robust touch languages that are easy to learn and use; moreover, beyond design, there is a lack of implementation and evaluation theories for such languages. To overcome these limitations, he proposed a unified, theoretical framework, inspired by natural, spoken language, called *Somatic ABC's* for Articulating (designing), Building (developing) and Confirming (evaluating) touch-based languages. To evaluate the usefulness of Somatic ABC's, its design, implementation and evaluation theories were applied to create communication languages for two very unique application areas: audio-described movies and motor learning. It was found that Somatic ABC's aided the design, development and evaluation of rich somatic languages with distinct and natural communication units.

Because the mission of SUITCEYES is to deploy a prototype which is wearable, combines situational awareness, visual analytics and face-to-face communication by the same ontology, and works in distance mode by default, our below approach is conceptual. Instead of haptemes to reproduce phonemes by graphemes by a combination of consecutive dots, dashes and strokes as in [2], we propose to use haptograms where the limited size and resolution of a body part as screen is counterbalanced by evolving patterns, i.e., the dynamics of signs. Our effort is in line with the approach by Israr and Poupyrev [6], building on their Tactile Brush approach, but focusing on language design by means of an ontology-compliant vocabulary vs. grammar, where the latter implements relational contextualization and sign sequencing. Thus, it belongs to the category of a priori defined spatial-temporal patterns in the semiotic vein.

The rest of the paper is structured as follows: Section 2 starts with an account of related research approaches, followed by Section 3 that provides a background on haptograms. Section 4 then introduces the SUITCEYES ontology that will play the role of the unified model for semantic integration of information from the environment, while Section 5 presents our approach for designing the haptogram vocabulary. Finally, Section 6 concludes the paper and gives insight into our future work directions.

II. RELATED RESEARCH

The phonemic approach to a haptic language by Lahtinen et al. [2] finds support from the study by Chen *et al*. [7], where they investigated that decomposing spoken or written language into phonemes and transcribing each phoneme into a unique vibrotactile pattern enables people to receive lexical messages on the arm. A potential barrier to adopting this new communication system is the time and effort required to learn the association between phonemes and vibrotactile patterns. However, their study was limited to the learning of 100 patterns by different methodologies, displayed on the arm, and the concepts were not connected to an ontology.

On the other hand, Reed *et al*. [8] experimented with a new tactile speech device based on the presentation of phonemic-based tactile codes. The device consisted of 24 tactors under independent control for stimulation at the elbow to wrist area. Using properties that included frequency and waveform of stimulation, amplitude, spatial location, and movement characteristics, unique tactile codes were designed for 39 consonant and vowel phonemes of the English language. The participants, 10 young adults, were then trained to identify sets of consonants and vowels, before being tested on the full set of 39 tactile codes.

Walker and Reed [9] investigated several haptic interfaces designed to reduce mistakes in Morse code reception of 12 characters. Results concluded that a bimanual setup, discriminating dots/dashes by left/right location, reduced the amount of errors to only 56.6% of the errors compared to a unimanual setup that used temporal discrimination to distinguish dots and dashes.

Very much in line with what we would like to achieve, Israr and Poupyrev in [6] proposed Tactile Brush, an algorithm that produces smooth, two-dimensional tactile moving strokes with varying frequency, intensity, velocity and direction of motion. The design of the algorithm was derived from the results of psychophysical investigations of two tactile illusions, *apparent tactile motion* and *phantom sensations*. Combined together they allowed for the design of high-density two-dimensional tactile displays using sparse vibrotactile arrays. In a series of experiments and evaluations, they demonstrated that Tactile Brush is robust and can reliably generate a wide variety of moving tactile sensations for a broad range of applications.

III. BACKGROUND ON HAPTOGRAMS

Haptograms as a concept were introduced by Korres and Eid [10]. In their approach, “Haptogram” is a system designed to provide point-cloud tactile display via acoustic radiation pressure. A tiled 2-D array of ultrasound transducers is used to produce a focal point that is animated to produce arbitrary 2-D and 3-D tactile shapes. The switching speed is very high, so that humans feel the distributed points simultaneously. The Haptogram system comprises a software component and a hardware component; the software component enables users to author and/or select a tactile object, create a point-cloud representation, and generate a sequence of focal points to drive the hardware.

Our haptograms, on the other hand, are conceptual, and correspond to ideograms and logograms in the tactile domain, using evolving dot patterns instead of tactile shapes. Further, we distinguish between *stable* vs. *changing* patterns and call them *static* vs. *dynamic* haptograms in a communication context. Their purpose in our framework is to implement an ontology-constrained messaging language to convey visual analytics results, situation awareness assessments, and everyday conversation raw material outside of the scope of the above two areas. As these haptograms are to be mapped to the back of a vest made of smart textile, i.e., use that body area to display semantic content, the resolution of this screen places a limit on the conceptual vocabulary. Since screen resolution goes back to the number of actuators in a rectangular grid, as a proof of concept, in the current arrangement we designed a test vocabulary of both static and dynamic dot patterns conveyed to the body by vibration, pressure, heat, stimulated position, their combinations, and combination sequences to map short messages from an external sender. This approach can be scaled up either by increasing actuator density, or by generating virtual actuators [6].

IV. THE SUITCEYES ONTOLOGY

The key aim of the SUITCEYES ontology is to semantically integrate information coming from the environment (via sensors), and from the system’s analysis components (e.g., visual analysis of camera feed). In this sense, the ontology is primarily focused on semantically representing aspects relevant to the users’ context, in order to provide them with enhanced situational awareness and augment their navigation and communication capabilities. More importantly, the proposed ontology also serves as the bridge between environmental cues and content communicated to the user via the haptograms described in the next section.

In ontology engineering, it is common practice to reuse existing third-party models and vocabularies during the development of a custom ontology. We also followed this approach, in order to rely on previously used and validated ontologies. We, thus, adopted the semantic representation of objects and activities from the Dem@Care ontology [11], [12], which contains a set of descriptions of every-day activities and common objects used in an every-day context that are highly relevant to our goals. Moreover, we are relying on SOSA/SSN [13] for representing sensors and the respective observations, and on the Friend-Of-A-Friend (FOAF) specification [14] for representing persons and social associations. Finally, we integrated the SEAS (Smart Energy Aware Systems) Building Ontology [15], which is a schema for describing the core topological concepts of a building, such as buildings, building spaces and rooms.

A. Ontology Conceptualisation

Figure 1 displays an overview of the core ontology classes based on the Grafoo ontology visualization notation [16]: the yellow rectangles represent classes, while the green ones represent data properties (i.e., properties that take a raw data value, like, e.g., integers and strings). The prefixes in front of some of the class names indicate the namespace of the respective third-party ontologies, as mentioned above. Classes and properties that have no prefix belong to the core SUITCEYES ontology.

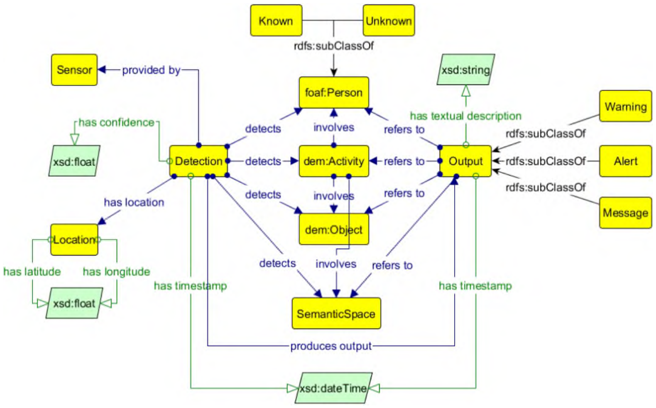

Figure 1. Overview of the core classes of the SUITCEYES ontology.

As indicated in the figure, class `Detection` is fundamental and refers to environmental cues (detected by the sensors) that have been instantiated in the ontology. A `Detection` instance may be associated with persons, objects, activities, and semantic spaces (more details on the latter follow next). The respective information is communicated to the user via class `Output` and its specializations: `Alert`, `Message`, `Warning`.

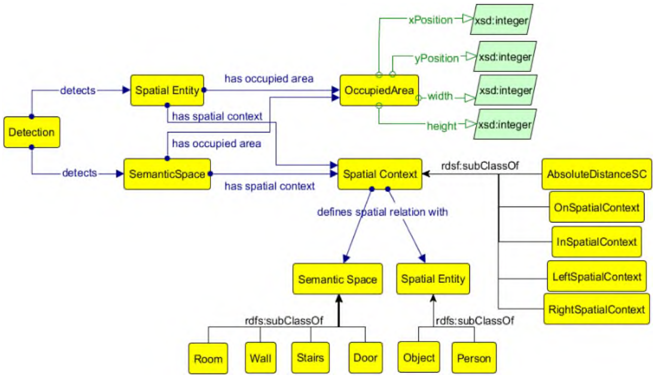

Figure 2. Semantic spaces and spatial contexts in the SUITCEYES ontology.

An entity that occupies space (e.g., persons, objects) is considered a `Spatial Entity` and the occupied space (e.g., a room or a location) belongs to the `Semantic Space` representation. These two aspects formulate the respective entity's `Spatial Context`, which provides information regarding the entity's relationship to the semantic space it is located in. Examples include: `in`, `on`, `left`, `right`, `far`, `close`, etc. The aforementioned concepts are depicted in Figure 2.

B. Sample Usage

Based on the ontological concepts presented above, Figure 3 illustrates a sample instantiation resembling an activity detected by the system's camera. The activity involves two people speaking to each other, one of them is known to the user (i.e., `john`) and the other is unknown. Moreover, these two people are currently located in the kitchen (i.e., `in_room_spatial_context`), and the respective message is communicated to the user via a textual description, which is then converted to haptograms as described in the next section.

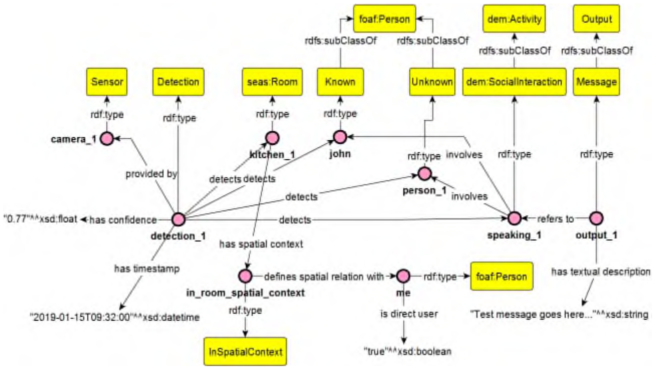

Figure 3. Sample instantiation of an activity involving two people discussing in the kitchen.

This flexible ontology-based representation described thus far allows the system to convey various types of information to the user. Below is an indicative list:

- Who is involved in an activity?
- Where is my mobile phone located?
- In which room am I now located?
- What objects are on the table?
- Which objects are observed on my left side?
- Which are the objects I am closer to/farther from?
- Alert! An obstacle (e.g., stairs) is in front of you!

V. HAPTOGRAM VOCABULARY DESIGN

Although in the next phase two-way communication will be our goal, in the current stage of the project our haptogramic vocabulary was designed for in-principle receiver testing over a 4 x 4 actuator grid. We were interested in finding out if the ontology and such a haptic conceptual vocabulary can be aligned, and how pattern sequences reminiscent of sentences can implement the transmission of more complex semantic content.

A. Examples

In our approach, haptograms can be static or dynamic, and can represent both word meaning and sentence meaning. Figure 4 illustrates the basic idea of the former version which was derived from the ASCII code table, where in our matrix cells, instead of characters, concepts are encoded.

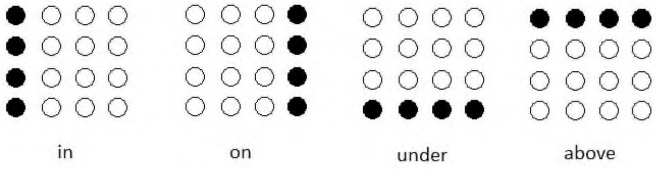

Figure 4. Sample static haptograms over a 4 x 4 actuator grid.

In Figure 5, we illustrate two sample dynamic haptograms. Above, in the matrix cells, the numbers indicate the firing sequence of the actuators for concepts (a) and (b), meaning "*stand*" and "*door*". Below the completed shape of the dynamic haptograms is indicated.

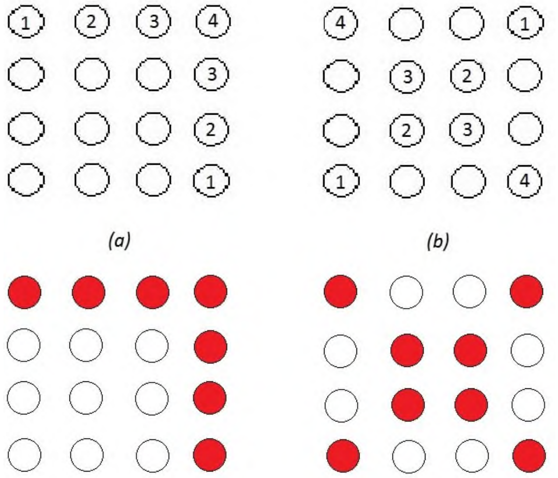

Figure 5. Unfolding sequences of two patterns over a 4 x 4 actuator grid, yielding different dynamic haptograms: (a) "*stand*"; (b) "*door*".

Moving over to sentence meaning, in Figure 6 we show how a simple statement, "*An unknown person is standing by/at the door*", can be made by concatenating static and dynamic haptograms. The statement begins with a single-blink sign, indicating the start of a new message, and finishes with a double-blink meaning end of transmission. It can be accompanied by a separate alert sign to add weight to the communicated content. Apart from this example, our test included questions and exclamations to enable a future dialogue between two users with deafblindness or a user with deafblindness and her/his trainer, family member, etc. Further, the vocabulary is both aligned with the ontology, and is including concepts and parts of speech not covered by the current version, i.e., indicates expansion opportunities. Likewise, e.g., logical operators, numbers, signs for operations etc. can be added following the same line of thought.

VI. CONCLUSION AND FUTURE WORK

We plan to update the current pattern generator to a maximum of 9 x 9 actuator size matrices, subject to feasibility evaluation by psychophysics to make sure users are able to easily and consequently distinguish between the communicated haptograms, a prerequisite of noise-free or low-noise communication. This could include adding numbers and ways of calculation to the haptogram kit for example. Parallel to this, new concepts and relations from ongoing ontology development will be mapped to a more systematically designed, structured set of static and dynamic haptograms so that their semantics, including statements and limited argumentation, can be easier to follow by users. A mobile sender unit will be added to the receiving kit to enable two-way communication, and we aim to extend the framework to sending messages over a distance as well.

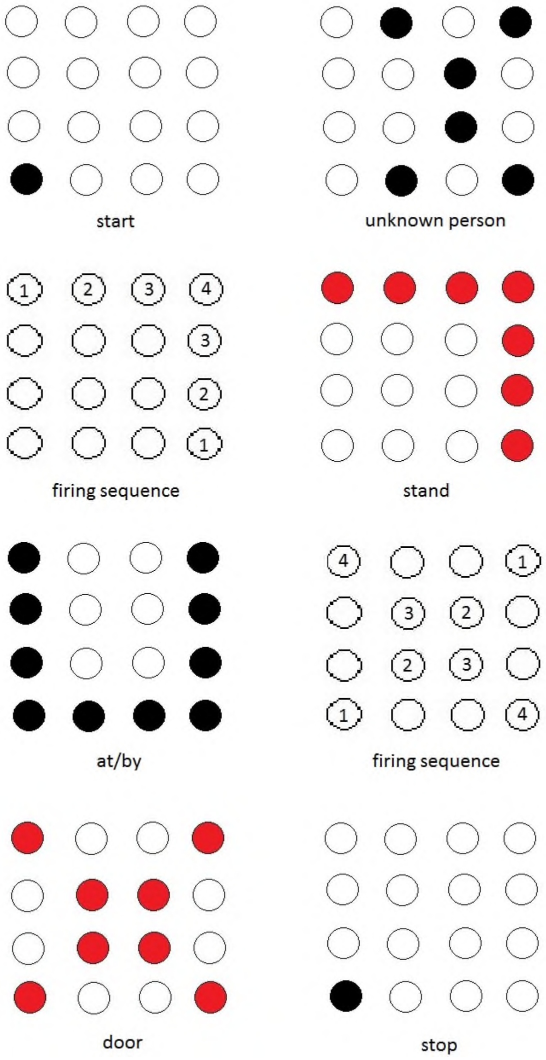

Figure 6. Sample statement constructed from static and dynamic haptograms over a 4 x 4 actuator grid: "Unknown person stand(ing) at/by (the) door".

In more detail, the current approach has its constraints by design, limiting incoming sensations and pattern recognition to the back of the individual. Given that this area is one of the less sensitive body interfaces for pattern recognition, an obvious way ahead will be to add more parts of the body as a screen, and combine pattern construction with diverse reception areas to extend the grammatical functionality of haptograms, while increasing the richness of the conceptual vocabulary. According to Lemmens et al. [17], for the torso, up to 62 sensors and actuators can be considered. This, combined with a more granular pattern generator, opens up new opportunities for a more systematic next effort, adding scalability to the approach, inviting knowledge graphs to replace ontologies, and increasing the number and complexity of situations to be described. One of the subsequent new challenges will be to match haptogram drawing on a mobile device by the sender over a much more sensitive surface, and its translation to the body.

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