Tactile Language Design

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The Tactile Language Design Methodology takes a systematic approach to the design of tactile communication. The methodology leverages the systems engineering lifecycle, research on human perception and the cognition of touch, and practical considerations for fielding a usable tactile communication system. Application of the methodology to the development of squad level tactile communications is presented to illustrate the use of the methodology.

INTRODUCTION

Tactile, or touch based, communication has long been used to interact with sensory impaired individuals. More recently attention has turned tactile communication as a means to complement or supplement traditional channels of communication, i.e., visual and auditory, in a wide range of applications. Tactile messaging utilizes the capability of a tactile hardware system to deliver combinations of individual tactor vibrations or bursts of stimulation to a user. These bursts are made up of tactile characteristics or parameters including frequency, amplitude, waveform, and duration, applied to different locations on the body. Combinations of these parameters can be used to create rhythm or patterns and produce discernibly distinct tactile 'words' called 'tactons'. Research is being performed at various military, academic and industry institutions addressing the questions regarding how to manipulate and combine these parameters to effectively convey mean in real world contexts. This paper presents the Tactile Language Design Methodology which leverages the empirical research and practical lessons learned for the design of tactile message sets. The use of the methodology is illustrated with an example application to the design of a tactile message set being developed for squad level Soldier communications.

TACTILE LANGUAGE DESIGN METHODOLOGY

Although a growing research base offers guidance in the manipulation of tactile parameters to convey meaning, tactile communication (for the non-sensory impaired) is a relatively new field, and few resources exist to guide the systematic creation of *complex tactile message sets*. In order to create effective tactile languages the Tactile Language Design Methodology integrates tactile language design guidance and concepts from the systems engineering process (requirements analysis, design, implementation, and evaluation) with practical steps for designing and implementing a tactile communication system.

The methodology (Figure 1) guides users in defining the messages to be translated into tactile 'words', with consideration of the constraints of the tactile parameters for the specified hardware upon which the messages will be played (Steps 1 and 2). Rules for translating messages into tactile representations are created based on the integration of best practices from the literature, characteristics of the message set and specific hardware capabilities (Step 3). Guidance is provided for using the design rules, combined with message metaphors to create tactile patterns that are intuitively representative of the message to be communicated, i.e., utilizing parameters that convey meaning linked to, or consistent with, meaning of the message (Step 4). Finally, the methodology recommends messages are evaluated for ease of learning and accuracy of interpretation (Step5).

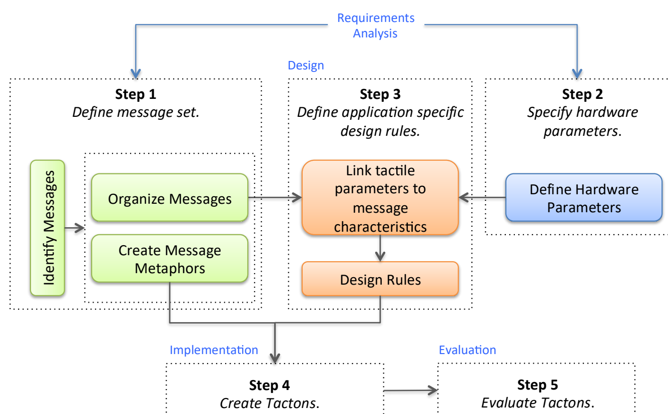


Figure 1. Tactile Language Design Methodology.

This methodology was developed as part of a DARPA funded project to facilitate the design of tactile messages to be used during squad level Soldier communications. The methodology and an abbreviated description of the application of the methodology (in italics) are presented.

Step 1: Defining the message set.

The scope of the message set may vary given the purpose of the language construction and the goals of the message designer. The designer may, for instance, be creating a comprehensive language intended to cover many different situations, or the designer may be designing messages appropriate for specific uses (e.g., recon mission operations, driving a car, facilitating multi user screen sharing among distributed CAD design team members). Either way it is critical to be thorough in defining the message set at the outset of the design process in order to design messages that are readily distinguishable from one another.

Defining the message set it is not only about 1) identifying the "words" or concepts to be communicated for the given task or situation, but also about 2) defining the relationships among the words and understanding the meaning of those words and how they are used in context in order to create tactile representations.

Identifying and organizing messages. In creating a language it is important to understand the kind of information that will be communicated via the language and the goals of the communication interactions. Commonly used methods for defining the necessary language include document review, task analysis, knowledge elicitation from subject matter experts, scenario-based walk through, and observation. Regardless of the method(s) used the goal of the analysis is to extract information that will facilitate the translation of messages into tactile representations as well as requirements and constraints on the implementation of messages in applied settings.

To create a usable system, message sets should include not only task specific content, but also messages that facilitate communication among users and between users and the system. In defining the message set considering the following types of messages: work related, user-system, and collaborative communication. *Work related* messages include human to human or technology to human communication about the primary work tasks. Descriptive or 'qualifying' information for instance, should also be considered, e.g., 'move out to the northeast' contains a base work related message - move out, along with qualifying information - northeast. *User-system related* reflect the state of the system to avoid misinterpretation by the user, e.g., 'replay' mode – indicating that the message being played is a duplicate of a message previously sent. *Collaborative Communication* messages facilitate rules or protocols used in communication (e.g., acknowledgement).

A structured message hierarchy should be created representing the major classes of information that will be contained in the language. The manner in which the categories and hierarchy of the taxonomy are created will have a considerable impact on the design of the messages and ultimately the ease of learning the language. As will be discussed in Step 3, certain characteristics of messages can be translated into tactile synonyms. Directional information for instance, has a spatial/geographical characteristic which can be readily represented by the tactor parameter, reflecting tactor position or body location. Tactile displays will be more intuitive if we capitalize on the capability of specific tactile parameters to communicate that meaning.

As part of the Soldier communication message project, messages were required to support common squad level communications as well as communications specific to a reconnaissance scenario. The message was defined through a group interview session with six active duty Soldiers at Ft Bragg, surveys given to Cadets at West Point Military Academy, and through working with two West Point instructors serving as subject matter experts.

A subset of Soldier communication messages, work related messages, are presented in Figure **2**. *Work related messages are broken down into situation awareness (SA) messages and Directive messages, which include Commands and Navigation. Messages in grey are considered 'base' messages and include the primary subject or concept being communicated, while qualifiers, in blue, provide additional information about the base message and are optional elements of a complete, complex message, i.e., qualifying information may or maybe be available to be communicated. For instance, looking at the SA portion of the figure, messages may be constructed to communicate information about an entity, red or blue entity and its class, personnel, observation post or minefield; along with optional descriptive information regarding direction, and/or proximity.*

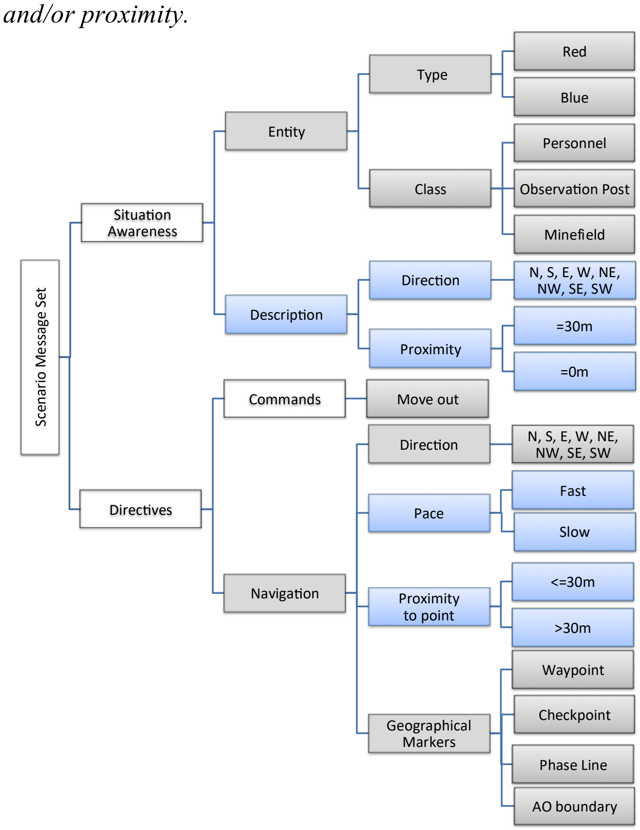


Figure 2. Message hierarchy.

Defining metaphors. Metaphors are effective in creating tactor burst patterns and rhythm that are easy to learn (Rosenthal, Edwards, Villanueva, Krishna, McDaniel & Panchanathan, 2011; Lee, Ryu & Choi, 2009; Chan, MacLean & McGrenere, 2008). During knowledge elicitation with SMEs developing a solid understanding of message meaning and how messages are used in context will help develop metaphors that can be represented tactilely. When considering the message, Halt, for instance, a metaphor of a barrier preventing the person from continuing forward can be used. Using a tactile hardware system comprising tactors embedded in a belt around the waist, halt might be instantiated as the tactors on the front of the belt being buzzed representing the feeling of walking into a barrier which forces the person to stop.

The metaphor for halt, described above is one example of a metaphor defined for Soldier communication. Additional examples include representing: enemy force with an alarm; entity types such as observation posts & personnel with shapes reflecting Army doctrine, triangle, and diamond, respectively; and move out by associating the concept of left /right, left/right marching.

Step 2. Specifying tactile design parameters.

As described in the introduction, tactile communication works by delivering patterns of vibrations to the skin through hardware devices termed, 'tactors' (conceptually similar to a cell phone vibrate mode). Characteristics of these vibrations can be controlled by manipulating a number of tactor parameters (similar to creating ring tones), i.e., by sending a particular waveform of a certain frequency and amplitude for a given amount of time to some location on the body.

Regardless of the specific tactor technology (e.g., electromechanical, piezoelectric, etc.), the tactile hardware will likely have the basic capabilities to manipulate the parameters listed above. Additional capabilities or constraints of the hardware system however should be identified. Understanding the capabilities and constraints of the system is important in determining the parameters available for manipulation.

Figure 3 *presents the tactile hardware used for the soldier tactile messaging research. Three layers of eight tactors and a 5X5 grid of tactors were embedded in a belt worn around the waist. Table 2 lists capabilities of the hardware for the current application to the methodology to Soldier tactile message design.*

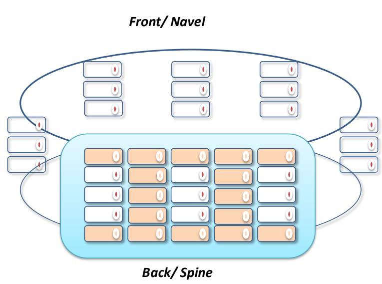


Figure 3. Tactile display hardware.

At the time of testing, the hardware was in a prototype stage and some limitations were identified: a maximum of eight the number of tactors that could be fired simultaneously due to power requirements; a ceiling on the amplitude (e.g., the controller was capable of delivering high amplitudes however the tactor could become unreliable under continuous use at high amplitudes); and specific waveforms (e.g., square wave) could not be maintained without hardware failures. Message design was bounded by these capabilities and constraints.

Step 3. Defining application-specific design rules.

Design rules are intended to facilitate standardized language construction and are derived by applying guidance from the tactile communication literature to the current design project – the message set and the hardware capabilities and constraints. The literature suggests tactile parameters can have implied meaning. If these meanings can be linked to the inherent meaning of messages within the message set, a mapping can be derived between tactile parameters and messages.
These message-parameter relationships should be defined to provide the foundation or starting point for developing the design rules to guide the translation of messages into a tactile language. For example, a message might be characterized by urgency. Urgency can be represented tactilely through rapid bursts of stimulation or by the rhythm; hence the message design can incorporate rapid bursts of stimulation. A number of reviews (Jones & Sarter, 2008; Brewster, & Brown, 2004; Gill, 2003; Gunther, et al., 2002) describe meaning inferred from specific tactile parameters. For instance, a sense of urgency has been found to be associated with burst duration, speed of tactile message delivery, increasing amplitude and/or frequency, and specific rhythms. Magnitude has been represented by area of activation, i.e., the size of area of body being stimulated, and burst and inter-burst durations. Categorical or type information has been defined by tactile rhythms. Movement or motion can be suggested through changing amplitude and spatiotemporal patterns. Spatial information can be represented through spatiotemporal patterns as well, and through burst duration and tactor position on the body. Temporal information has been associated with tactile rhythms and patterns.

Messages can have inherent or inferred meaning as well. Messages and/or message categories in the message set should be analyzed for characteristics that can be represented tactilely. For example, a sense of urgency may be inferred from a message indicting that an enemy force is nearby. As noted above, a sense of urgency can be represented via specific tactile parameters such as burst duration and speed of message delivery. In message design, burst duration and speed of delivery can be used to impart a sense of urgency for messages that are inherently urgent. These message–tactile parameter associations can be capitalized on to make the tactile representations of messages as intuitive as possible.
In addition to mapping messages to parameters, design rules should also specify specific parameter values to be used (e.g., 0ms for a 'short' inter-burst duration). Use the literature to establish 'best practice' based default parameter values, e.g., frequency of 250hz (Self, van Erp,. Eriksson & Elliott, 2008; Jones & Sarter, 2008; Gill, 2003) and ranges, as well as guidelines for deviating from default parameters (which consider effective range values and potential interaction with other parameters). In creating default values, the messages that the parameters are intended to support were considered. Pace, for instance, can be represented by interburst duration. If in a message set, Pace is defined at one of two levels, either slow or fast, only 2 levels of pace needed to be represented tactilely. Therefore, two levels of interburst durations would need to be established, one to be used when representing slow and one for fast.

Table 1 shows linkages between messages and tactile parameters through a common perceptual characteristic (for a subset of the Soldier communication messages).

Table 1. Linkage of perceptual characteristics of message with tactile parameter (partial message list).

Example Message	*Perceptual Characteristic*	*Tactile parameters associated with characteristic*
Direction (e.g., N, S, E, W)	***Geospatial***	*Tactor location*
Proximity to point	***Geospatial***	*Burst Duration*
Geographical markers (e.g., waypoint)	***Categorical/ Type***	*Spatiotemporal pattern; shape*
Pace (e.g., fast, slow)	***Temporal***	*Rhythm – burst/interburst duration*

Figure 4 below applies the message – parameter mapping to the message hierarchy. Navigation messages including direction and proximity have Geospatial characteristics. As de-

scribed above, geospatial characteristics can be represented tactilely through tactor location and burst duration; hence these parameters were used in the translation of this navigational information to tactile messages. Geographical markers for navigation are categorical in nature and were represented through patterns and shapes. Finally, pace contains a temporal component, which was represented through manipulation of inter-burst durations. These relationships provided the foundation for message set specific design rules.

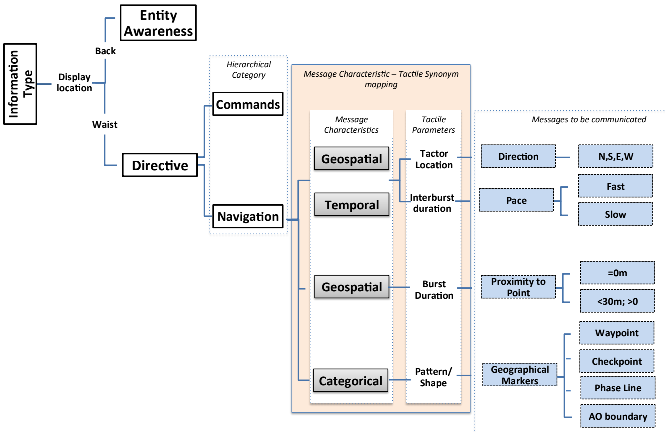


Figure 4. ***Example message hierarchy integrated with message characteristics and tactile parameters.***

Rules derived from the portion of the message hierarchy shown in Figure 4 *are high level and include: 1) all navigational messages (and commands) are presented on the 3-layer portion of the belt going around the waist. The belt provides an eight point navigational reference system mapping to eight compass points (N,S,E,W,NE,NW,SE,SW). Geospatial aspects of navigation, including direction and proximity to a point on the route, are communicated through tactor location, and on/off burst duration rhythm. The direction of movement involves the location or position of the tactor on the body - around the torso, representing the direction to travel; while proximity is represented by the rhythm of bursts– with long bursts indicating further distance and short bursts indicating close proximity.*

Table 2 lists default parameter for the current application to the methodology to Soldier tactile message design and Figure 5 *demonstrates the application of the default parameter values to the messages.*

Table 2. Hardware capabilities and default parameter values.

Parameter	***Hardware capabilities***	***Default values***
Amplitude	*1-8*	*Highest, without exceeding 26db*
Frequency	*up to 500hz*	*250Hz*
Waveform	*Sine, triangle*	*Sine*
Location	*40 tactors*	*Torso & 5x5 grid; Tactor Spacing 3-4cms; aligned with body parts, e.g., navel, spine*
Burst duration (on)	*0-infinity*	*'Normal = 300ms; Short = 80ms; Long = 800ms*
Interburst interval (off)	*0- infinity*	*'Normal = 80; Short = 0; Long = 150*
Pattern	*Max 8 simultaneous tactors*	*Message specific*

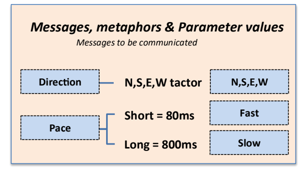


Figure 5. Parameter values applied to message hierarchy.

Step 4. Creating tactons.

Now that the basic building blocks are defined (parameters and values) to enhance he intuitiveness of tactile messages, the tactile patterns are created. The process of translating simple words or messages into their tactile counterparts is illustrated in Figure 6, along with the combination of simple tactons to form complex tactons. To create a simple or 'base' tacton for a given message, concept or word, rules governing the effective implementation of the parameters are combined with the metaphor associated with the word (Step 1) to create a unique combination of tactile stimulation to represent that word or message. For example, using 'navigation' as a message and a metaphor of a 'traffic arrow' used on roads to indicate traffic patterns, design rules can be applied to specify the parameter values - location, burst and interburst durations, amplitude and frequency – required to create a tactile 'traffic arrow'.

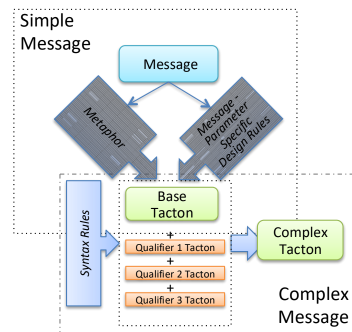


Figure 6. Simple and complex tacton.

Simple messages such as navigation may have additional descriptive information (qualifiers), e.g., direction, distance and pace. Tactile representations of these qualifiers can be derived in a similar fashion (using metaphor and design rules) and combined with the simple tacton. The literature describes several approaches to syntax development when combining tactons, including compound, hierarchical and transformational (Brewster and Brown; 2004).

These approaches can be considered singly or in combination to develop the syntax rules that will govern the tactile language. *Compound displays* involve combining individual tactons in an additive fashion to form a meaningful compound tacton. In the *hierarchical* approach, tactons (representing hierarchical concepts or information) can be organized in a hierarchical tree fashion with lower level tactons inheriting the properties of higher level tactons. Using a *transformational* approach, specific tactor parameters reflect some property of the message or hold some meaning. For example, all enemy related messages might use a square waveform which is annoying, while messages regarding friendlies might use a smoother, less irritating waveform, such as a sine wave.

A standard notation should be created for tactons. Tactile messages can be represented visually for ease of communication, however the design should also be represented in a manner that facilitates authoring in the tactile display system.

Tacton designs were represented in graphical and tabular form. Tactons including the one shown in Figure 7 were created and documented.

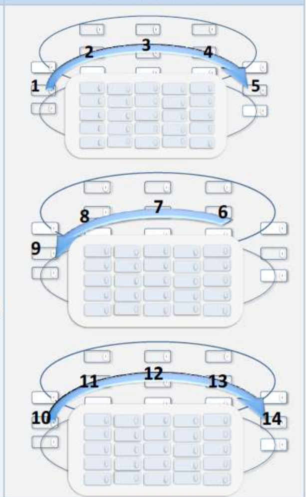
Message	Metaphor or rationale	Implementation Description	Tacton graphical representation
Inside Named Area of Interest (NAI)	Visual scanning – While defining the message set it was determined that upon entering an NAI Soldiers begin looking for specified targets. With this in mind a visual scanning metaphor was created: scanning from left to the right and back to the left again	• Tactor bursts begin at the West tactor, row 2 (top figure, tactor #1), with each consecutive tactor firing until reaching the East tactor, row 2 (top figure, tactor #5) • back to West tactor, row 2 • back to West tactor, row 2 again • Short burst duration with 0 inter-burst duration • Default frequency and amplitude	

Figure 7. Sample tacton documentation.

Combing messages for use in Soldier communication involved the integration of the three approaches to developing complex messages. The compound approach was leveraged to add qualifiers to simple messages. The simple message was played followed by any qualifiers. Given the hierarchical nature of the message set, the hierarchical approach is reflected in the assignment of message categories (SA versus navigation and commands) to specific tactor locations associated with the 'belt' versus the 'grid'. All messages within the SA branch of the hierarchy were assigned to the grid, while messages within the Directives branch of the hierarchy were assigned to the 3-layer portion of the belt. Finally, the transformational approach leveraged the perceptual characteristics of multiple tactor parameters in creating design rules.

Step 5: Evaluate tactile message set.

A key concept in the systems engineering lifecycle is iterative evaluation. Throughout the design process multiple informal evaluations should typically take place, e.g., defining a tactor parameter as a synonyms for a particular message characteristic implementing it and informally trying it out to determine if the tactile representation really does feel like or imply the message characteristic. In addition to these informal iterative evaluations, more formal evaluations are also critical. Two types of evaluation are suggested: 1) design, and 2) performance. The design evaluation is lab study conducted to evaluate tacton designs and influence design decisions, while the performance evaluation is a validation study of the effectiveness of the tactile system to support user activities in more applied environments. Upon completion of the evaluations the message set, design rules, and tacton designs should be refined and the final tactile message set should be documented.

The first level of evaluation – design evaluation - was conducted at the United States Military Academy, West Point, utilizing cadets in a lab study to evaluate the design of individual messages as well as the syntax for combining base messages into complex message. A description of the studies can be found in Chapman and Riddle (2012). The utility of evaluation for tactile message design is illustrated by the research validating certain messages and identifying messages in need of modification. For instance, results indicated that users have difficulty with judgments of absolute (versus relative) differences in burst duration; as a result design rules defining the of use burst duration to represent categories along a continuum – near, moderate, far, and slow, normal, fast, were revisited.

DISCUSSION

The methodology provides a practical approach to designing tactile messages using best practices from the literature and iteratively designing, implementing, and evaluating messages before making refinements and finalizing the message set.

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