SELF-ORGANIZATION OF THE COMMUNICATION SPACE BASED ON USER RANGE-OF-MOTION: A FRAMEWORK FOR CONFIGURING NON-CONTACT AUGMENTATIVE COMMUNICATION DEVICES

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Abstract. Augmentative communication devices are traditionally used by individuals with chronic communication disabilities. Recently, there has been a growing interest in deploying augmentative communication technologies when individuals temporarily and suddenly lose the ability to speak, due for example, to surgery, mechanical ventilation or disease advancement. Due to the complex and evolving physical needs in these settings, flexible non-contact communication devices are proposed as potential communication solutions. Non-contact communication devices typically translate some form of intentional movement of a user into an interface navigation command (e.g. mouse emulation) or directly into a target message (e.g. yes or no). Even with a modest vocabulary, optimally configuring a user's communication space by hand can be a time-consuming process that needs to be repeated when the user's vocabulary needs or physical abilities change. We propose a general methodology for computer-vision based communication devices whereby the communication space can be configured automatically through mathematical optimization. The objectives of such optimization are to maximally exploit the reachable space, to minimize probability of user error and to minimize the user's average effort in reaching given target messages. In addition, self-organization of the communication space observes constraints reflecting the user's range of movement. We present a simple realization of this general methodology and exemplify some results obtained using a sample of a communication space.

INTRODUCTION

Voicelessness and communication

Voicelessness is the inability to speak. Happ (2000) frames voicelessness as a contextual process where physiological, psychosocial and technological barriers limit a patient's ability to convey their thoughts, feelings and needs fully to others. The consequences of transient voicelessness are far reaching. In various studies, patients reported feelings of depersonalization, loss of control, isolation and fear arising from the inability to speak (See for example, Jablonski, 1994; Fitch, 1987). Feelings of stress in nursing staff have been associated with failure and frustration at not being able to understand the voiceless patient (Happ, 2001). Anecdotal accounts of misinterpreting behaviours of voiceless patients are voluminous and often heart-wrenching (e.g. Happ, 2000). For example, irritable behaviour due to discomfort from an undetected bedsore was misinterpreted and dismissed by nurses as violent tendencies (Hospital for Sick Children, Neurooncology staff, personal communication, September 2002).

Gestures in communication

Gestures form a vital part of discourse known as the paralinguistic channel (Fex and Mansson, 1998). Facial expressions, eye movements, hand and arm motions and head positions are examples of natural gestures, which may convey meaning in normal conversation. Connolly (1992) found that most gestural communication in temporarily voiceless patients addressed basic needs such as "pain medication", "suction me", "water" and "sleep". Gestures used by voiceless patients are predominantly emblematic such as the "o.k." hand symbol and deictic (pointing) (Happ, 2001). While emblematic gestures convey meaning without the accompaniment of speech, mutually understood "emblems" are often few in number. On the other hand, deictic gestures may often be difficult to interpret in context, but due to their simplicity and variety, may represent an untapped communication potential in temporarily voiceless patients.

AAC interventions

There have been very few published studies of augmentative and alternative communication (AAC) interventions in patients who have transient voicelessness. A picture board representing basic needs (pain, fear, thirst, bedpan, hot/cold) improved post-surgical nurse-patient communication among temporarily intubated cardiothoracic surgical patients (Stovksy and Rudy, 1988). A combination of AAC tools including digital voice banking using voice output communication aids and various access methods such as QWERTY keyboard or single switches were introduced pre-operatively to paediatric patients at Children's Hospital in Boston (Costello, 2000). Patients and families expressed satisfaction with the communication interventions and found them to be non-fatiguing.

Augmented environments

Augmented reality systems can endow the physical space surrounding an individual with additional properties it otherwise would not have, thereby creating an augmented environment (Fuhrmann et al., 1999; Azuma et al., 2001). Using video images as the system input, for example, access to the augmented environment can be facilitated through natural gestures (Camurri and Ferrentino, 1999). In this way, the interface is "non-contact" meaning that the user does not interact with physical devices, such as a switch, button or joystick (Reilly and O'Malley, 1999; Clarke et al., 1998). Such environments can also be tailored to the precise sensory and motor capacities of the individual (Rose et al., 1997). In this way, augmented environments can potentially facilitate enriched communication regardless of the level of sensory or motor function. For example, simply by gesturing with a finger within the neighbouring physical space, an individual may activate a "virtual" switch, which in turn, may trigger a computer to say "I am in pain". Due to this unprecedented flexibility, augmented and virtual environments have been recently exploited in the rehabilitation of visuospatial skills (Rizzo et al., 2001), fine motor tasks (Holden et al., 2001) and perceptual-motor skills (Inman et al., 1997) in children with disabilities.

OBJECTIVE

The overall objective of this research is to develop an algorithm for automatically demarcating the communication space based on the available range-of-motion of the patient.

Definitions

The communication space is defined as the region, within which an individual comfortably gestures to express his or her intentions. Communication objects are objects of any geometric shape drawn into the communication space to represent vocabulary, complete messages or selected letters. These objects can be with or without iconic symbols. For simplicity, in this study we assume the communication space is a two-dimensional mapping of an individual's three-dimensional movement space, and the communication objects are circles defined by the following equation:

$$\{m_i(x,y) \mid (x-c_x)^2+(y-c_y)^2 \le r_i^2\}, \quad i=1,2,..M \qquad (1)$$

where m_i is the i^{th} communication objects with the radius r_i *and centre* (c_x,c_y).

Objective Function

Figure 1 illustrates an example of a communication space overlaid with the contours of a Range of Motion (ROM). ROM probability distribution is a bivariate probability distribution representing the individual's range of motion. High probabilities identify region of space within which the user is likely to gesture. Three communication objects with centre points C_1,C_2 and C_3 have been placed into the communication space.

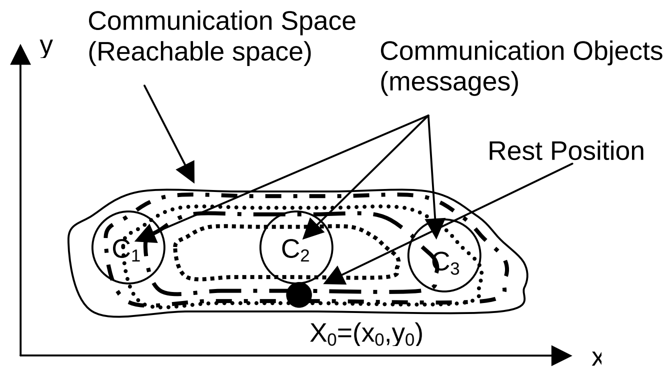

Figure 1. An example of a communication space overlaid with the contours of a Range of Motion (ROM)

Our objective is to:

1. Maximally exploit the reachable space and minimizing probability of inadvertent co-activation of neighbouring messages by maximizing intermessage distance.

2. Minimize the distance of messages from the rest position.

Therefore the objective function J, can be defined as:

$$J(C_1, C_2, ..., C_M) = \frac{\prod_{i}^{M} d(C_i, X_0)}{\prod_{i}^{M}\prod_{j\neq i}^{M} d_{ij}} \qquad (2)$$

where C_i is the centre of the i^{th} communication object, M is the number of messages (usually less than 5),

$d_{ij} \neq 0$ is the Euclidian distances between the centres of the i^{th} and j^{th} communication objects (intermessage distance) and $d(C_i,X_0)$ is the Euclidian distance from the centre of the i^{th} communication object to the resting point. Our goal is to minimize the objective function $J(C_1,C_2,\ldots C_M)$ with respect to the following constraint:

$$\iint_{x,y} f(x,y)dxdy \geq \delta \qquad (3)$$

where $f(x,y)$ is the joint probability density function of the communication space and *d is* the minimum desired probability. It can be easily seen that in order to minimize $J(C_1,C_2,\ldots C_M)$, the numerator should be minimized while the denominator should be maximized.

SIMULATION AND RESULTS

Augmented environment construction

In this simulation we decided to put three communication objects within the communication space. For this study, a Logitech web cam with a CMOS sensor was used to capture live images and a MATLAB program was developed to process the images and apply the optimization algorithm. While capturing live images, an individual moved his hand to define the ROM. One hundred true colour (RGB) frames were captured and converted to greyscale. The first and the last captured frames are shown in Figures 2.a and 2.b. In order to find the moving pixels, the differences between frames were calculated so that the static parts of the frames (Background) were eliminated. It should be noted that as CMOS web cams do not produce clear live images, some static pixels appeared as moving pixels (background noise), which were eliminated by applying an intensity threshold to these pixels. In order to obtain the total ROM, all the processed frames were normalized and added together. A Median filter was then applied to remove residual background noise and to smooth out the ROM density. This produced the density of ROM, which is shown in Figure 2.c.

Optimization

The optimization was initiated with three randomly selected feasible points within the ROM boundaries. The constraint was evaluated over a 10x10 block centred on the pixel in question. The constrained optimization problem was solved using the Sequential Quadratic Programming method (Fletcher, 1963,1987; Goldfarb, 1970) within the MATLAB environment. The minimum desired probability (*d*), was set at 0.4. A contour of the estimated density superimposed with the estimated results, i.e. the estimated locations of the communication objects and the reference point (*X0*) are plotted in Figure 2.d.

DISCUSSION AND CONCLUSION

The optimization algorithm tries to maximize the distances between the communication object centres, while minimizing the distance from each of these points to the reference point. All of these points satisfy the constraint given in equation 3. In real applications, we want to set the minimum desired probability high enough (greater than 0.8) to ensure the communication objects are placed on the regions where the user is likely to easily access them. Increasing the minimum desired probability might cause the algorithm not to converge for some of the trials. One improvement technique may be choosing a kernel function as a density function estimator to supply more accurate density estimation as the constraint for the optimization algorithm.

The identified optimal locations in the communication space would be where communication objects would be placed for a non-contact communication aid. Qualitatively, it appears that the optimization process has selected locations that are reasonably spread out in regions of high probability and not too distant from the reference point.

In conclusion, we have demonstrated that it is possible to self-organize communication objects for a non-contact communication aid on the basis of a user's range-of-motion. Future work will include the investigation of additional constraints of more complex movements, and improvements of the density function estimator.

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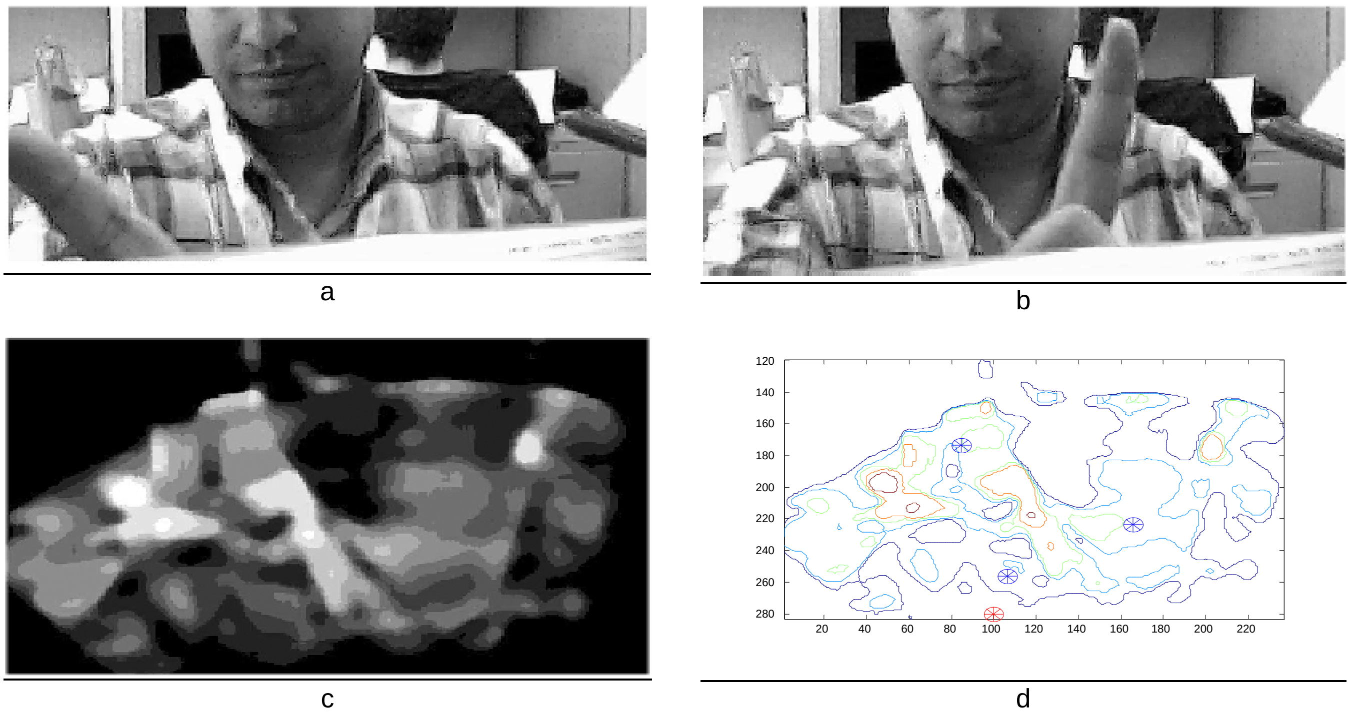

Figure 2. Samples of captured frames for ROM estimation. a) The first captured frame of a trial to estimate ROM. b) The last captured frame of a trial to estimate ROM. c) Estimated ROM, which is the actual communication space. d) Estimated communication objects locations. The reference point is located at X0=(100,280)

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