Modeling Reach for use in User Interface Design

Aaron P. Toney and Bruce H. Thomas
School of Computer & Information Science
University of South Australia,

aaron.toney@hhhh.org, bruce.thomas@unisa.edu.au

Abstract

This paper presents the anthropometric parameters of reach as a central concern to both tangible and direct touch user interface design. The paper begins with an introduction to existing literature on reach modeling. As the models in the literature were intended for a stationary individual, a user study was conducted measuring impact of freedom of motion on the maximum reported comfortable reach envelope. The study showed the impact on workspace usage caused by changes in the user's body position, orientation, and in the working surfaces height and shape. Finally, the paper presents several ways in which these reach models can be immediately applied to user interface design.

Keywords: Reach, Physical Context, Tangible, Direct Touch, Reach Envelope, User Interface Design

1 Introduction

Every time you effortlessly find a hand rail or a button on a dashboard in a "natural" position, you are experiencing the product of industrial designers intelligently applying anthropometric models. Designers of everyday objects like buildings, cars, and appliances regularly use these models to appropriately fit their designs to the intended users. Currently, creating user interfaces whose elements are just as "natural" to use is an open problem for the HCI community. This paper proposes building on the anthropometric tools currently used by the industrial design community to build user interfaces that are tailored to their users.

Since reach impacts every aspect of a person's physical interaction with their environment, through familiarity people develop a rich and accurate set of expectations and intuitions about reach. As a result, user interface designers have detailed intuitions about the context of their applications. What they lack, and what reach models pro-vide, is a powerful way to turn user intuition into qualitative algorithmic descriptions that guide the behavior of their designs. Intuitions about reach such as "objects near the body are more easily manipulated" or "ease of object manipulation falls off as the manipulated object moves away from the body" are of little use programmatically. At that level they are only able to grossly shape the design of a user interface by statically influencing the choices made by the designers. The models of reach presented in this paper allow designers of tangible and direct touch user interfaces (Ullmer and Ishii 1997; Ullmer, Ishii et al. 1998; Ullmer and Ishii 2000) to encode their high-level human intuition.

In addition to describing reach, anthropometric models of reach establish a quantitative meaning for relational terms such as "near","far", or "close" to the user. Using these definitions, designers are able to let the user's reach have runtime influence over their applications. Tangible and direct touch applications that detect their user's anthropometric parameters at runtime are able to dynamically scale and position the user interface elements so as to never be out of the users reach. Practically, this means that a component of a user interface can be constructed to be just as usable for a person who is 4'8" as it is for a per-son who is 6'3". For collaborative applications, this means that applications can be developed that support both user extremes at the same time.

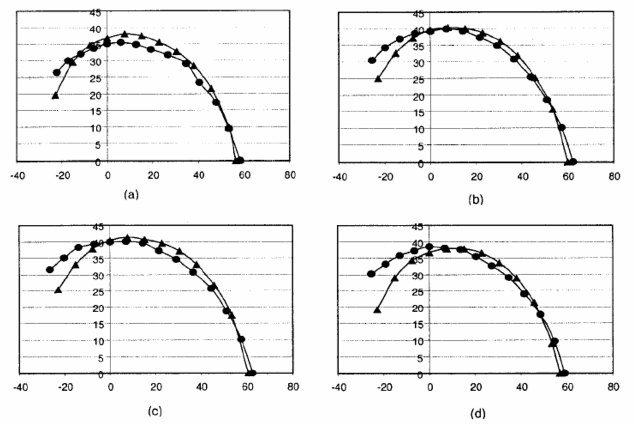
This paper is the first to propose applying anthropometric models of reach to the design of tangible and direct touch user interfaces. After a quick review of the relevant literature the results of a twenty-one person user study measuring the reach envelope for a comfortably seated user are presented. The study explored the impact of comfortable user motion on reach. Finally, several examples are given in which reach can be used for the creation of dynamic user interfaces.

2 Obtaining Anthropometric Data

Anthropometric modeling can be built using either directly observed anthropometric characteristics of the current user, or statistically derived characteristics for an intended target population. Where statistical anthropometric data is required, the authors strongly recommend NASA's Man-Systems Integration Standards (NASA 1995) for range of motion data, and the U.S. Marine Corps Anthropometric database and its supplements for anthropometric dimensions (Donelson and Gordon 1996; Paquette, Gordon et al. 1997).

3 Quantitative Models of Reach

Sengupta (Sengupta and Das 2000), "Maximum reach envelope for the seated and standing male and female for industrial workspace design", presents a solid review of the literature before going on to present the results of a user study measuring reach for seated and standing industrial workstation users. Most significantly, Sengupta provides tables of their data for the 5th, 50th, and 95th percentile maximum reach envelopes. The presented data covers both seated and standing individuals of both genders measured at several heights above the working surface. Figure 1 shows Sengupta's comparison of their work (Sengupta and Das 2000) and the work of Faulkner (Faulkner and Day 1970) measured at 0, 15, 30, 45, and 60cm above the working surface.



●Sengupta & Das(2000) (Sengupta and Das 2000) and
▲Faulkner & Day(1970)(Faulkner and Day 1970)

Figure 1 Reach measured at 0, 15, 45, and 60 cm above the working surface

4 User Study: The Impact of Motion on Reach

Existing studies of reach have all constrained the subject position with respect to the table. For example, in (Faulkner and Day 1970) the subjects chair was positioned to place their torso against the edge of the table. Sengupta (Sengupta and Das 2000) fixed subjects with their torsos 2.5cm from the table edge. In both studies physical constraints were used to restrict motion of the subject's torso. What was missing from the literature was a measure of the impact of user motion on maximum reach. The authors ran a user study to gather this data. The study examined seated comfortable reach.

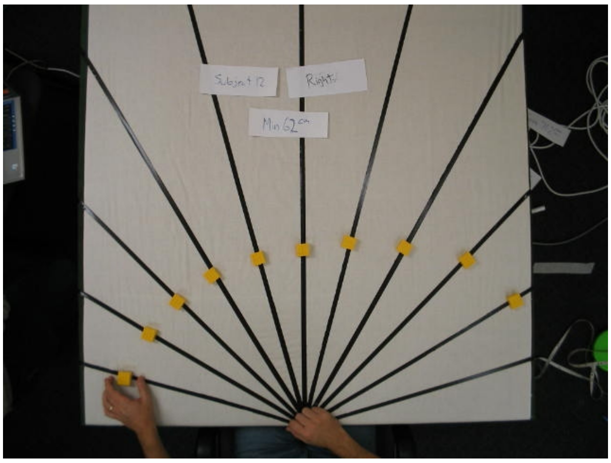


Figure 2 Measuring the on-table reach envelope

In the study, users were allowed to move during measurement as long as they stayed firmly, but comfortably, seated. While subjects were asked to keep their backs comfortably resting on their seatback, no mechanical restraints were used as in earlier studies. The study also recorded the users' reported comfortable table height and distance from the working surface.

Twenty one subjects were run as part of the study, recruited from the faculty and student population of the University of South Australia. For the study, subjects were told to center their body on the indicated mid-line for the table (shown in Figure 2). No physical or verbal cues were given to help the users to "square their body" with the edge of the table. Rails on the floor prevented the subjects chair from moving laterally. The rails were used to align and hold the resting position of the sagittal plane of the subject's torso with the table edge.

A powered height adjustable table enabled users to easily alter the current table height. For all users the table was initially set to a height of 73.5cm. Subjects were asked to seat themselves at a comfortable working distance from the table at this height. Subjects were then asked to adjust the table height to two different subjective table heights. First, what they felt was their minimum comfortable working height, and then to their ideal working height. Subjects were instructed to select heights assuming they would be performing a task working with a large number of elements such as assembling a puzzle or model.

The table surface was divided into eleven angular sections in 15 degree increments as shown in Figure 2. Subjects were instructed to "place a series of tiles radially outwards along the indicated lines as far as they could". At each of the table heights (minimum, comfortable, and maximum working heights), distances were recorded corresponding to the distance of the tile from the intersection of the sagittal plane of the body and the edge of the table nearest the user.

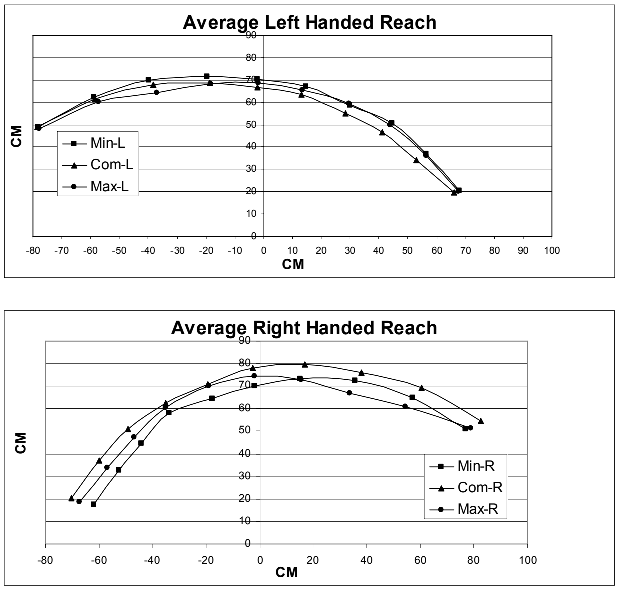


Figure 3 Examples of measured comfortable reach

4.1 Comfortable Working Height

The average reported comfortable working height was 68cm with a standard deviation of 1.83cm. The height of the seat pan for the chair used in the study was 42cm. Typically, in ergonomics and industrial design, the ideal working plane is placed at the height of the elbow measured with the arm hanging freely and the body in a relaxed posture. Under this definition the ideal working place for a subject was predicted to be the seat pan height, plus their torso height, minus their shoulder to elbow distance. Using this definition the average ideal table height predicted across all users was 60.46cm. Reported comfortable shoulder height deviated from this globally predicted height by an average of 7.55cm (or 8%). For individual users, the reported comfortable reach deviated from that predicted by shoulder to elbow distance by an average of 4.72cm. The corresponding deviation from the reported minimum workable table height was 2.74cm with a standard deviation from the predicted height of 5.05cm.

4.2 Distance from the Table

The observed distance from the table across the 21 subjects ran ranged from 10.5 to 23cm from the table. The average distance from the table was 17.07cm with a standard deviation of 3.28cm.

4.3 Maximum on Table Reach`

Across all users in the study, a reach was observed to have a symmetrical elliptical nature with relatively shallow maximum penetration into the table. (See Figure 3 for a representative example of the observed results for one of the subjects). When corrected to account for user motion and the average comfortable working distance the observations in the study agree with those reported in previous literature. Most significantly when corrected for the user being at a comfortable distance from the working surface the results reported by (Sengupta and Das 2000) show on-table reach to be even shallower than initially expected. Correcting with a working depth of 17cm from the table edge their results predict, seated-maximum-reach for the 95th percentile of the population will penetrate the working surface only 42 cm for males and 38 cm for females. For the 5th percentile of the population reach is predicted to penetrate the working surface 24 cm for males and 20.cm for females.

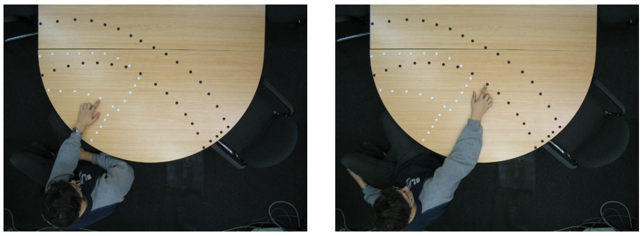
4.4 User Motion and Reach

The user study measured the reach envelope for a moving user while existing literature reported the reach envelope for a user at a fixed position. Comparing the two sets of observations indicates that for reachable area of a stationary user (S_R), the reachable area for that user moving over a time (t) can be expressed as ($S_R \rightarrow \cup_t S_R$). As a result, the models of reach that exist in the literature, once corrected to account for user motion, are suitable for use in user dynamic reach driven user interface design.

The "comfortable" range of motion for a seated user was observed to be highly subjective. The range of reported comfortable motion for subjects in the current study ranged from conservative, exhibiting very little motion keeping their back firmly in the seat-back, to aggressive, with the users practically jumping out of their seat in order to maximize their reach. This suggests that reachable area over time ($\cup_t S_R$) should be calculated with at least some runtime sampling of the user's position, and should not rely solely on derived statistical models.

5 Body Orientation and Reach

The torso shadows reachable space. Users seated at a table commonly orient themselves relative to objects in their environment rather than to the table. Orientation impacts the reachable space on the table. The note taking depicted in Figure 5 is a common example of this behaviour. As the user orientates them selves with an off-table information source, such as a speaker or large display, their on-table reach is attenuated. Figure 4 shows the comfortable and maximum reach for the left and right hand (described in (Toney and Thomas 2005). The darker tiles represent the reach envelope for the right hand while the white points represent the reach envelope for the left hand. The reachable space is constrained within a maximum and minimum adduction and abduction angles (NASA 1995; Wang, Das et al. 1999). Figure 4 (A) and Figure 5 illustrates how the torso shadows the left hands on-table reach.



(A) Adduction (B) Abduction

Figure 4 Adduction (A) and Abduction (B) in Reach

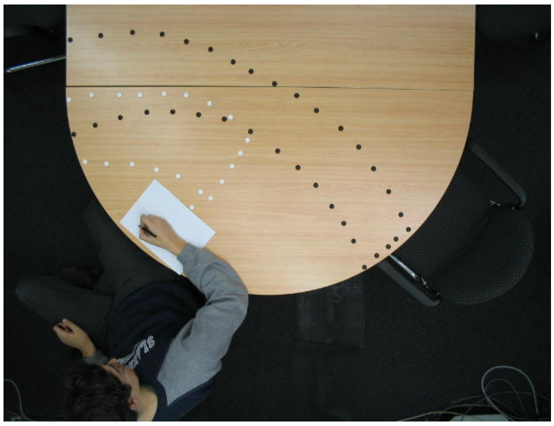


Figure 5 Note Taking

6 The Dynamic Reach Envelope

The dynamic reach envelope, or kinetosphere, describes the set of all reachable points for a subject at a given position. This shell of reachable space, when it is intersected with the working plane, provides what we have been referring to as the reach envelope. The literature (such as in Figure 1) provide a volume of reach sampled at various heights above the working plane. As a result the techniques proposed in this paper are applicable to user inter-faces that have gesture or object manipulation components (Ivan Poupyrev, Mark Billinghurst et al. 1996; Ken Hinckley, Randy Pausch et al. 1998) that take place above the working surface.

7 Applications of Reach Models in UI Design

In collaboration with NICTA, the Wearable Computing Laboratory at the University of South Australia is researching the benefits of applying anthropometric models of reach in designing user interfaces for large horizontal interactive displays. The next stage of the research is taking place on the NICTA Visualization and Interaction over Collaborative Access Tables (VICAT). The project employs three tabletop displays with Access Grid nodes at three geographically different locations. Each table, or CAT, consists of a vertical projection area and one back-projected horizontal area, as shown in Figure 6. The horizontal display supplies the working area for the direct touch and tangible user interfaces.

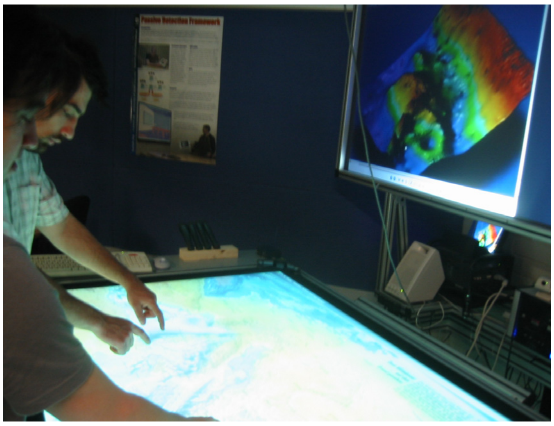


Figure 6 Use of a large horizontal interactive display

7.1 Ensuring Reachability for UI Elements

Since both direct touch and tangible user interfaces are by their nature constrained to areas of reachable space, the reach envelope for the user $(\bigcup_i S_R)$ determines the envelope for the user accessible interface elements. Direct touch user interfaces can be assured that elements rendered inside of this envelope will be reachable by their user. In tangible user interfaces, used in a collaborative context, awareness of reach position makes possible movement cues to encourage users to keep shared user interface elements within a central reachable area.

7.2 Predicting Table Segmentation

For collocated collaborators overlapping reach envelopes are being investigates as a way to predict natural places for public and private interaction regions on the working surface. The hypothesis is that for a single workspace the optimal places for "public" interaction spaces in tangible and direct touch user interfaces are in areas reachable by all of the collocated collaborating parties.

7.3 Scaling User Interfaces

For remote collaborators models of reach are being investigated as a way to uniquely map the local collaborative interaction spaces into a common space equally accessible to all collaborators. In this way when a user moves a shared user interface element to his maximum reach its remote counterpart, mapped onto the local display, will still be reachable by a collaborator with a smaller maximum reach. This type of dynamic user interface allows for a 4'8" collaborator to have the same presence in a remote collaboration as a 6'3" collaborator.

Additionally the reach envelope provides a maximum distance from the user. This distance implicitly creates a zero to reach length scale that applies to all interface objects. The objects distance from the user can be used to dynamically control the user interface as in (Ivan Poupyrev, Mark Billinghurst et al. 1996).

8 Conclusion

This provides, for the first time, powerful tools for the run time tailoring of the user interface to its current users. A user study has shown that existing models of reach for stationary users used in industrial design and ergonomics can be adapted to the needs of a user interface design. Initial comfortable height and working distance from the working plane were established by the presented study. Finally the paper presents several ways in which the presented tools can immediately start being used by the human computer interaction (HCI) community.

9 References

Donelson, S. M. and C. Gordon (1996). 1995 Matched Anthropometric database of U.S.Marine Corps Personnel: Summary Statistics, United States Army Soldier Systems Command.

Faulkner, R. R. and R. A. Day (1970). "The maximum functional reach for the female operator,." IIE Transactions, **2**: 126-131.

Faulkner, R. R. and R. A. Day (1970). "The maximum functional reach for the female operator." IIE Transactions **2**: 126-131.

Ivan Poupyrev, Mark Billinghurst, et al. (1996). The Go-Go Interaction Technique: Non-linear Mapping for Direct Manipulation in VR. ACM Symposium on User Interface Software and Technology.

Ken Hinckley, Randy Pausch, et al. (1998). ACM Transactions on Computer-Human Interaction **5**(3): 260-302.

NASA (1995). Man-Systems Integration Standards, Revision B.

Paquette, S. P., C. Gordon, et al. (1997). A Supplement to the 1995 matched anthropometric database of U.S. Marine corps personnel: summary statistics. Natick, Massachusetts, United States Army.

Sengupta, A. K. and B. Das (2000). "Maximum reach envelope for the seated and standing male and female for industrial workstation design." Ergonomics **43**(9): 1390-1404.

Toney, A. and B. H. Thomas (2005). Considering Reach in Tangible and Tabltop Design. TableTop, Adelaide, IEEE.

Ullmer, B. and H. Ishii (1997). The metaDESK: Models and Prototypes for Tangible User Interfaces. UIST, ACM.

Ullmer, B. and H. Ishii (2000). "Emerging frameworks for tangible user interfaces." IBM Systems Journal **39**(NOS 3&4).

Ullmer, B., H. Ishii, et al. (1998). mediaBlocks: Physical Containers, Transports, and Controls for Online Media. SIGRAPH, ACM.

Wang, Y., B. Das, et al. (1999). "Normal horizontal working area: the concept of inner boundary." Ergonomics **42**(4): 638-646.