Modeling reach for use in user interface design

Aaron P. Toney, Bruce H. Thomas
School of Computer and Information Science
University of South Australia
aaron.toney@hhhh.org, bruce.thomas@unisa.edu.au

Abstract

The area on a horizontal working plane usable for direct manipulation or direct touch user interfaces is constrained within the space reachable by the users. This paper shows that existing models of reach in the literature are suitable for use in user interface design. While existing data was gathered for stationary individuals this paper examines the impact of freedom of motion on the maximum reported comfortable reach envelope (i.e. the surface of maximum reach). A user study was conducted to gauge the impact at several table heights of user motion on available working space. Throughout, the paper discuses several ways in which these reach models can be immediately applied to user interface design.

Keywords: Reach, Physical context, Tangible, Direct touch, Reach envelope

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 applied anthropometric models. Designers of everyday objects like buildings, cars, and appliances regularly use anthropometric models to tailor their designs to their intended user population. Currently, creating user interfaces whose elements are just as "natural" to use is an open problem. This paper proposes building on the anthropometric tools currently used by other design communities to create user interfaces that are dynamically tailored to their current users. For direct manipulation and direct touch user interfaces the first step in this process is to be able to predict the envelope of reachable space from observations of the user.

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 provide, is a powerful way to turn user intuition into qualitative algorithmic descriptions that guide the behaviour 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 work of this paper shows the existing models of reach in the literature are suitable for use by 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.

By combining intuition encoded as simple thesis with anthropometric models of reach can establish a quantitative meaning for the normally subjective terms such as "near", "far", or "close" with respect to the user. For example by deciding that "far" means being more then two thirds the users maximum reach away, or that "close" means being less then a third of the maximum reach away, anthropometric models can provide a hard numeric descriptions for these previously subjective terms. Since the intuitions are no longer subjected they can be tested and the proven intuitions used to drive user interface design. This paper showed that existing models of reach were suitable for generating these descriptions for populations of users. Other work by the authors (Toney and Thomas 2006) has started exploring how dynamic modeling of the users can empower dynamic user interfaces.

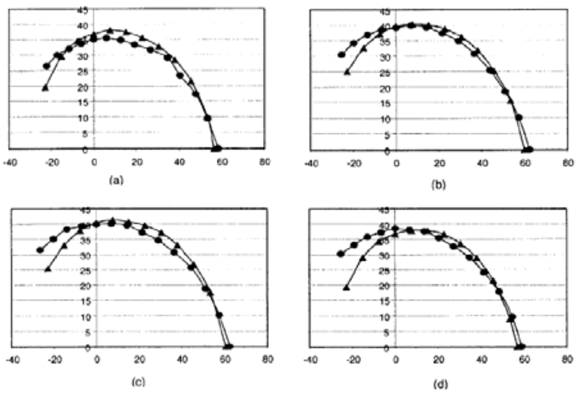
Using these definitions, designers are able to let the user's reach have runtime influence over their applications. Tangible and direct touch applications that detect their user's anthropometric parameters at runtime are able to dynamically scale and position the user interface elements so as to never 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 person who is 6'3". If the users are remotely located models of reach help establish scaling constants for actions and data shared across displays. In a collocated context models of reach can guide placement and size of user interface elements; for example ensuring that shared user interface elements are placed in "public" spaces reachable by both users.

2 Obtaining anthropometric data

Anthropometric modeling can be either directly observed anthropometric characteristics of the current user, or statistically derived characteristics for the 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

In "Maximum reach envelope for the seated and standing male and female for industrial workspace design" (Sengupta and Das 2000) Sengupta presents a solid review of the literature before going on to present the results of their 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 0, 15, 30, 45, and 60cm above the working surface. Figure 1 shows a comparison of Sengupta's (Sengupta and Das 2000) and Faulkner's (Faulkner and Day 1970) results.



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

Figure 1 Reach envelope measured at (a)0, (b)15, (c)45, and (d)60 centimeters 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 (Faulkner and Day 1970) the subjects chair was positioned to place their torso against the edge of the table. While Sengupta and Das (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 user's seated comfortable reach.

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 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 student population of the University of South Australia. The subjects used were chosen to be representative of the population as a whole in terms of both gender and handedness. 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 squared the chair with table and 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 was used enabled users to easily alter the current table height. For all users the table was initially set to its maximum adjustable height at 73.5cm. This represented the maximum working height for the study. 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 workable 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 physical elements such as assembling a puzzle or model.

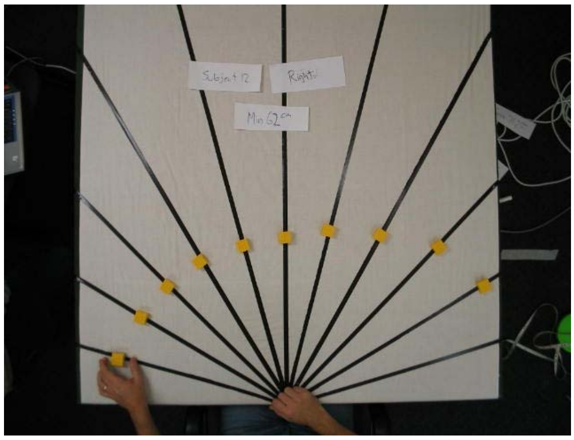


Figure 2 Measuring the on-table reach envelope

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 user selected working heights (minimum, comfortable, and maximum), 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 (the intersection point of the lines on the table).

4.1 Distance from the Table

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

4.2 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 plane 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 average minimum workable table height of 62.5cm was 2.74cm with a standard deviation from the predicted height of 5.05cm.

4.3 Observed Maximum on Table Reach

Across all users in the study, 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). These observed results agreed with the earlier reported results in the literature. For example, when corrected to account for our observed average comfortable working distance, the results reported by Sengupta (Sengupta and Das 2000) show on table reach to be even shallower than initially expected. At a working depth of 17cm from the table edge, seated-maximum-reach will penetrate the ideal working plane only 42cm (male) and 38cm (female) for the 95th percentile population, and 24cm (male) and 20.1cm (female) for the 5th percentile of the population.

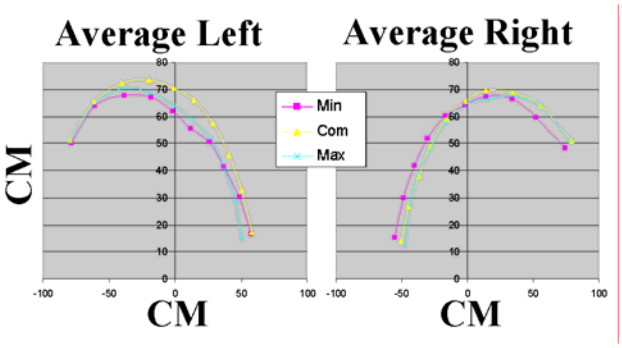


Figure 3 Example of Measured Reach with user Motion. (The center of the user's torso is at origin.)

The practical implications for user interfaces that are not scaled to fit their current user are that over 95% of users will either be unable to reach, or will have to move and stretch to reach, user interface elements that are more then 38-42cm from the table edge. If a user interface element needs to be reachable by over 95% of the population it needs to be placed within ~20cm of the table edge. These are maximum numbers that roll off with distance from the sagittal plane of the user's body.

4.4 The Impact of User Motion on Maximum 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 suggests 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 ($S_R \rightarrow \bigcup_t S_R$). Where $\rightarrow$ can be read as "becomes" or "becomes equivalent to" for the purposes of this paper. 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 interface design where the motion of the user is known.

4.5 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 interfaces (Ivan Poupyrev, Mark Billinghurst et al. 1996; Ken Hinckley, Randy Pausch et al. 1998) that have gesture or object manipulation components that take place above the working surface.

4.6 Range of comfortable motion

The single most surprising result from the user study was the range in responses to comfortable user motion among the subjects. Subjects ranged from conservative, exhibiting very little motion keeping their back firmly in the seatback, to aggressive with the users practically jumping out of their set in order to increase their reach.

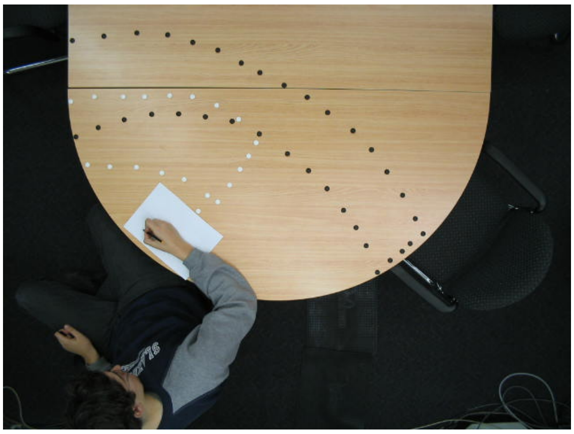


Figure 4 Note Taking

4.7 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 not relative to the table impacts the reachable space on the table. The note taking depicted in Figure 4 is a common example of this behavior Figure 5 shows the comfortable and maximum reach for the left and right hand (described in (Toney and Thomas 2006)). The darker tiles represent the reach envelope for the right hand (A_R) while the white points represent the reach envelope for the left hand (A_L).

The reachable space is constrained within a maximum and minimum adduction and abduction angles (NASA 1995; Wang, Das et al. 1999). The adduction angle represents the torso blocking rigid arm movement.

(A) Adduction (B) Abduction

Figure 5 Adduction (A) and abduction (B) in reach space

5 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. The vertical displays will be used for video conferencing; while the horizontal display supplies the main working area.

5.1 Ensuring all UI Elements are Reachable

Since both direct touch and tangible user interfaces are by their nature constrained to areas of reachable space, the reach envelope for the user ($\bigcup_t S_R$) 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 collaborative tangible user interfaces, awareness of position makes possible movement cues to encourage users to keep shared user interface elements within a central area reachable by all users.

5.2 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” places in tangible and direct touch user interfaces are in areas reachable by all of the collocated collaborating parties.

5.3 Scaling User Interfaces

For remote collaborators models of reach are being investigated as a way to uniquely map each of the local collaborative display space into a common space equally accessible by all group members. In this way when a 6’3” 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 4’8” collaborator.

The reach envelop 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).

6 Conclusion

This paper has presented reach as a powerful tool for user interface design. 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, with an active user. Initial parameters of the comfortable working plane in terms of height and distance from the user were also established by the study.

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