Exploring the Effects of Target Location Size and Position System Accuracy on Location Based Applications*

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Abstract. We describe an examination of various physical and human factors which influence the effectiveness of location-based applications. By varying both the target location size and position system accuracy, and hence the ease of use of an application, we are able to identify physical constraints which apply as well as quantifying performance and evaluating human factors. A movement analysis is proposed which allows us to formulate a set of equations that relate the time to find the target to the target location size, distance and positioning system accuracy. We validate our work using a game based application, digital hopscotch, in which the location size and the accuracy of the positioning system are varied. A further set of tests is performed outdoors using a GPS-based application. We show that the results from these experiments concur with the results from our equations. This work may be usefully embedded in software packages that allow designers to build location-based applications.

1 Introduction

Location-based applications for mobile computing have become of increasing interest to the research community, and are entering daily usage by the general public. Examples of this range from GPS-based navigation systems for vehicles and pedestrians, 'where's my nearest' applications for mobile phones and, increasingly, Geographic Information Systems (GIS) which associate information with geographic co-ordinates. Emerging applications include gaming and location-based entertainment. In this paper we explore physical aspects which affect the performance of applications, in particular the parameters of the location or target, and also the specification of the position sensing system. As part of this continuing research we are seeking to contribute to methods for the objective evaluation of such systems.

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The class of applications which particularly interests us are those in which digital information is associated with a real location. Examples of this type of application include museum guides where background information is provided about nearby exhibits [1, 2]; tourist guides again providing context related information to users [3, 4]; and mediascapes where sound and images are presented at particular locations to provide a multimedia experience [5, 6].

The information is accessed by a user who employs a position sensing system, such as GPS or ultrasonics, to determine coincidence between the user and the location. Confusion can be caused by the words 'position' and 'location' being used as synonyms (examples of dictionary definitions of position are "a strategic point" and of location "a particular place"). We define a location as a place, or target area, with an assigned label. We define a position as a point in space with specified 3D coordinates and a known error distribution. Our definitions are consistent with Hightower and Borriello's descriptions of 'physical position' and 'symbolic location' [7]. Examples of location are thus a known area such as Cambridge (within the City Boundary), or MacDonalds (inside the restaurant building); and examples of position are 51deg 32.78min N, 2deg 15.35min W, altitude 102m, with a standard deviation of 5m; or x=15.45m, y=6.28m, z=-7.14m relative to a known fixed origin with a 30cm standard deviation. We have used standard deviation as this does not assume a particular error distribution.

We assume that the user of a location-based system has to travel a variable distance to reach a location where the digital information is revealed. The performance of such a location-based application often depends on the accuracy of the position sensing system. A GPS-based city tourist system that correctly identifies which part of a street the user is on is considered acceptable, however a similar system based on mobile phone cell recognition would be of little use.

In this paper we use an ultrasonic positioning system indoors to facilitate a simple game of hopscotch with a PDA interface, and then apply our findings to a similar outdoor application using GPS. By varying the target location size, and for the indoor case, the positioning accuracy, we have collected suitable data to enable us to propose a relationship between location size, positioning accuracy and application effectiveness. The baseline tests were carried out in such a way as to be able to enable to consider the results according to gender, age and relative difficulty of the task (i.e. getting easier or harder).

While much work has already been undertaken examining similar issues for desktop computing, little has been done to objectively assess the relative performance of positioning systems for location-based applications. We believe that a games based approach has the potential to contribute to this line of research.

We first outline theories relating to target acquisition, then describe in detail our indoor location test scenario based on the children's hopscotch game, and then report on our findings with the outdoor GPS-based application. Finally we discuss the results and make our conclusions.

2 Theory

In this section we discuss two possible approaches to analysis of the effects of location size and positioning system characteristics. The first is a physical analysis of the human movements in a location-based application and the second is the well established Fitts' Law, commonly used for pointing analysis though also applicable to target acquisition.

2.1 Movement Analysis

The time taken to acquire a target has two major components. First the time taken to move from the current position to the boundary of the new target area and, secondly, the time required to carry out the search necessary to trigger the application. The search is needed as error in the positioning system may result in false readings which do not trigger the application even though the user has arrived at the physical target area. The search time will also be affected by the update rate of the positioning system as the more often the reading is updated, the sooner a match will be obtained. The overall time can thus be expressed as:

$$T_a = (d - r)/v + 1/(fp) \tag{1}$$

where T_a is the overall time; d is the distance to the centre of the target location, r the radius of the target - and hence $(d-r)$ is the distance to the boundary; v is the average velocity of the user; f is the update rate of the positioning system; and p is the probability of a trigger point being found. This probability can be expressed as the area of the target location divided by the area of uncertainty of the positioning system:

$$p = \pi r^2/(\pi(k\sigma)^2) \tag{2}$$

where k is a constant representing the error distribution and σ is the standard deviation of the positioning system. Note that the term $\pi(k\sigma)^2$ can be refined if the error distribution is known.

Taking equations 1 and 2 together we have:

$$T_a = (d - r)/v + k^2\sigma^2/(fr^2) \tag{3}$$

These equations form the basis of our hypothesis, however we require an alternative approach to test the usefulness of our thinking. We have chosen Fitts' Law as a potentially suitable comparator.

2.2 Fitts' Law

Extensive research has already been carried out into the acquisition of targets, particularly for desktop computer systems, and has resulted in many variations of Fitts' Law [8]. This law states that the time taken to acquire a target is a function of the distance to, and size of, the target. Mathematically this can be expressed as:

$$T = a + b\, log_2(D/S + c) \tag{4}$$

where T = time to move the hand to a target, D = distance between hand and target, S = size (width) of target, and a,b & c are constants, with a or c usually equal to one. $Log_2(D/S + c)$ is known as the Index of Difficulty (IOD).

Fitts' Law is a powerful tool for predicting the performance of a *pointing* based application, usually involving a mouse and screen interface. The objective of Fitts' Law is analogous in the real world to the physical acquisition of a target location by a moving subject. However additional factors need to be considered. The speed with which a mouse pointer traverses a display screen is assumed not to have a first order effect while the speed of a moving subject is patently relevant to the time needed to move to a location in the real world. The accuracy of the positioning of a mouse pointer can also be determined to the nearest pixel, whereas in the real world we are subject to the vagaries of physical position measurement. We would thus expect that for a location-based application, the time taken to acquire a target will also depend on the speed of the user and the characteristics of the position measurement system.

In the following section we test the applicability of both equation 3 and Fitts' Law to a real indoor application, and discuss the validity of our results.

3 Indoor Test Scenario

The elements which we require to test our hypotheses include a measured position, a target location, a distance to be traversed, and the performance of test subjects measured in time. These requirements can be fulfilled by creating a PDA based game requiring the player to move between a number of bases, or targets. For the results to be meaningful it is necessary for some form of unpredictability to be incorporated to prevent the player second guessing the system.

3.1 Position Sensing

There are many indoor position sensing technologies available for research purposes [7]. For our experiments we require a system which will provide coverage over a limited area with an accuracy predicted to be greater than that needed for the chosen application. GPS accuracy, while suitable for navigation at street level, has proved problematic at smaller scales [9]. The accuracies provided by systems integrating ultrasonics or magnetic sensing with inertial techniques [10, 11] far exceed our anticipated needs, and do not provide coverage over a large enough area.

For our requirements we have used the Bristol ultrasonic positioning system with a reference RF signal and a measured standard deviation(σ) of 5.7cm [12]. This system relies on a synchronising RF pulse followed by a number of timed ultrasonic signals transmitted from known positions in the infrastructure. A receiver decodes these signals and provides a position to a wearable or handheld computer.

3.2 Digital Hopscotch

The children's game of 'hopscotch' comes close to meeting our requirements and has inspired our design. In this game the player moves across a grid, or pattern of bases, in a predetermined sequence. There are many variations of this game, however for our purposes we wish to create uniform, but still unpredictable, paths for the players to follow. A pattern of eight circles, or bases, whose size for detection purposes can be varied for each game, can be used to provide six equally long paths which can be chosen at random (see Figure 1). The positions of the bases and path are chosen to ensure that the distance from each base to the next on the path is identical. For example, paths [*start-1-3-4-6-end*], [*start-1-3-5-6-end*] and [*start-2-4-3-5-end*] are all the same length. The size of the base circle is set within the application software, with its centre being indicated by a marker on the floor (see Figure 2). We do not require the player to 'hop' as the PDA and positioning system introduce sufficient handicaps!

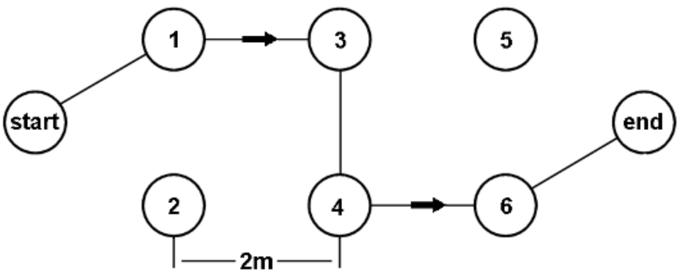

Fig. 1. Layout and typical path

Fig. 2. iPAQ, with ultrasonic sensor, and hopscotch layout

The player is guided along the chosen path by a PDA with a position sensor attached. The PDA displays the number of the base to be located (see Figure 2). Success at reaching each base is determined using the positioning system. The accuracy of the system can be degraded with the addition of random, but statistically limited, error values. After each base is found the number of the next base in the path is displayed on the PDA. By timing each player from start to finish, and combining this with the varying location size, we expect to be able to identify relationships between the variables.

Twenty volunteers, 10 females and 10 males took part in the baseline experiment. In the age range 18-24 years there was one female; in the 25-34 years range there were five females and four males; there were three females and three males between 35 and 44 years and one female and three males were over 45 years.

Based on pilot studies we defined five experimental conditions. In the first condition each target had a diameter of 200 centimetres, for the second condition this was set at 100 centimetres, for the third at 50 centimetres, the fourth at 25 centimetres and for the last, and hardest, the detection size was 12.5 centimetres. Individual experimental sessions were short, no longer than ten minutes, and as a consequence, although subjects had to complete five experimental conditions, this did not result in experimental fatigue.

There were two orders of presenting the experimental conditions: the first from large to small (starting with the 200 cm size, followed by the 100 cm size and subsequently the 50, 25 and 12.5 cm sizes); the second order of presentation was the reverse, from small to large. Half of the subjects (five females and five males) followed the first order of presentation, from large to small, whereas the other half followed the second order of presentation from small to large.

To detect differences, between genders, order of presentation of experimental conditions, age and most importantly between experimental conditions, we carried out several flavours of the analysis of variance (ANOVA). To investigate similarities between the conditions, i.e. to examine if subjects who were fast (or slow) in one condition were also fast (or slow) in the other conditions, we used the product moment correlation coefficient.

The statistic associated with ANOVA is the F-ratio (F) with two accompanying sets of degrees of freedom (df) and the product moment correlation coefficient (r). Both statistics provide an indication of how much the results could have come about by chance alone. This is denoted by the probability (p) value and, in general, a result is called statistically significant if the p-value is 0.05 or smaller.

Further tests were carried out with random subjects using limited noise values added to the sensed positions to degrade the accuracy of the position sensing system. These tests enabled us to examine the effect of positioning system accuracy on the game's effectiveness.

3.3 Baseline Test Procedure

Each test consisted of five movements between bases two metres apart, commencing at a 'start' base and ending at a 'finish' base. The tests were repeated consecutively five times with the base target area either increasing from test to test, or decreasing. The smallest base diameter was 0.125m and the largest 2.0m. A factor of two was used to increase/decrease the difficulty between tests. Thus each participant provided 25 results. Participants were given a single familiarisation test before readings were recorded.

The bases were designated by bright orange plinths 30cm dia by 25cm high with the relevant marking on top. The participants carried an iPAQ PDA with an ultrasonic receiver attached (see Figure 2). They were told that there was a trigger point somewhere above the top of the plinth where the PDA receiver had to be held, and that height was not a factor. The PDA would confirm that the target had been reached by displaying the number of next target. A researcher stands by to resolve any misunderstandings, and to encourage the player to continue searching where the base circle is small relative to the positioning accuracy, and thus hard to find.

User Behaviour and Analysis. The time taken by each subject to complete the course was analysed using ANOVA. There were no differences between the performances of females and males nor did age have an effect. The order of presentation of the experimental conditions (large to small or small to large) also did not result in significant differences. We therefore collapsed all these factors and further statistical results are shown across the group as a whole. We compared each condition with the other conditions and all paired comparisons resulted in highly significant F-ratios (all p-values were well below 0.01, see Table 1. Thus we can conclude that each of the five conditions is significantly different from the other. The means and standard deviations for each condition are given in Figure 3.

Oddly enough there were no significant correlations between conditions. Thus if a volunteer was fast in one condition then this did not automatically mean that

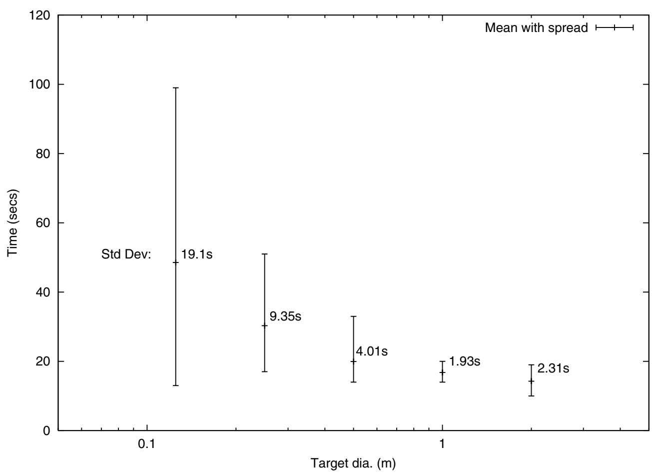

Fig. 3. Baseline Results - Mean Times, Spread and Standard Deviation

Table 1. Paired comparisons between conditions

Size	100 cm	50 cm	25 cm	12.5 cm
200cm	$F(1,19) = 24.48$ $p < 0.001$	$F(1,19) = 42.12$ $p < 0.001$	$F(1,19) = 51.66$ $p < 0.001$	$F(1,19) = 33.25$ $p < 0.001$
100cm		$F(1,19) = 11.14$ $p = 0.003$	$F(1,19) = 42.05$ $p < 0.001$	$F(1,19) = 31.25$ $p < 0.001$
50cm			$F(1,19) = 18.26$ $p < 0.001$	$F(1,19) = 28.95$ $p < 0.001$
25cm				$F(1,19) = 23.83$ $p < 0.001$

this subject was also fast in the next condition (and vice versa), although for the first order of presenting the experimental conditions, where subjects started with the easiest conditions there was one significant correlation between the 200 cm and 100 cm, i.e. the first two conditions, r = 0.76, df = 9, p =0 .01 . In the 200cm and 100cm conditions, the dominant time appears to be walking between the bases, so the correlation is probably walking speed. For the smaller targets there is an acquisition time as well (walking then searching). So for the different conditions, significantly different (in the day-to-day sense) mechanisms dominate the times.

Movement Analysis. Applying Equation 3 to our hopscotch game, with an estimated walking speed of 0.5m/s and the positioning system updating at 1Hz, we see the resulting curve combined with our actual resulting times in Figure 4. It was necessary to estimate the walking speed due to the stop/start nature of the exercise prohibiting normal walking speeds being reached. Actual walking speed measurements were later used for the outdoor GPS application. We used

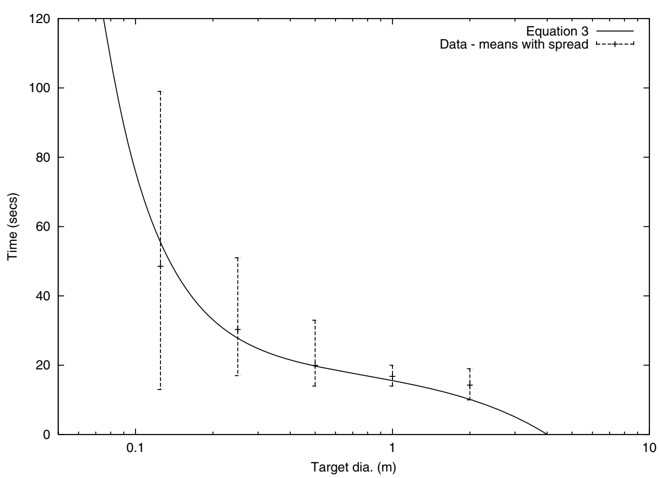

Fig. 4. Movement Analysis with Data Points

a value of k=3 which would represent a 99.7 per cent value for a normal error distribution (3σ). Figure 4 indicates a close relationship between our observed data and the hypothetical curve. We carried out a regression analysis on this data and a correlation coefficient of 0.94 was obtained. This indicates a good match between the recorded data and the hypothesis.

The figure illustrates an anomaly with the target location at 2m diameter. This is probably due to the uncertainty of the start point - with a location diameter of 2m there is likely to be a significant error due to the variability in the position of the start point. With smaller locations the participants ensured that they were actually at the centre of the location - the game thus became haphazard with 2m diameter targets.

Correspondence with Fitts' law. To confirm the consistency of our data with Fitts' Law we should obtain a straight line result when our resulting times per game are plotted against the IOD (Index of Difficulty). See Figure 5. The x-axis is the Index of Difficulty $log_2(D/S+1)$ where D is the distance to the target (in our case 2m) and S is the (variable) size of the target. The results used are the means of the data collected for each target size and are shown where the size S is taken to be the diameter of the target. We observe that for the case where the target diameter is 12.5 cm - the highest IOD in each case - then the results clearly do not correspond with Fitts' Law. We believe that this is because a boundary condition is being approached. Except in special cases, it is not possible to achieve a target which is smaller than the resolution of the position detection system. There are further boundary conditions which we discovered in our preliminary tests - these are where our target locations overlap, and ultimately where our target size is greater than, or equal to, the size of our world (or playing area). Excluding the 12.5 cm case from our analysis we carried out a regression analysis and achieved a correlation coefficient with Fitts' Law of 0.58 - a poor match.

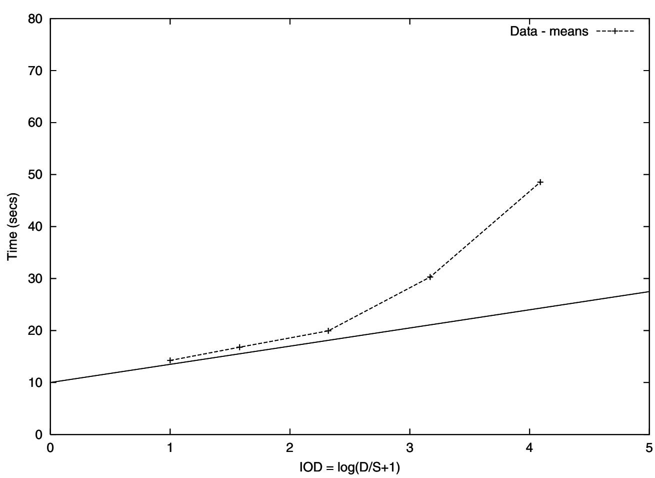

Fig. 5. Fitts' Law - Index of Difficulty

We also note that Fitts' Law was devised for systems where the target is visible. It is important to realise that the target in our tests is actually *virtual*. The target location is not displayed in the real world, it exists in our application's memory and is only represented by our hopscotch bases. It is easier to understand Fitts' Law if one considers the control task of hand-eye coordination. This is an interaction - one moves the mouse (or other pointer), the eyes see the movement, you correct and repeat until the target is reached. Our hopscotch game does not consist of a series of successive movements to acquire each target. Fitts' Law thus appears not to be appropriate in this case but nevertheless provides an interesting counterpoint to our movement analysis.

3.4 Accuracy Tests

The baseline tests investigated the effect of changing target sizes, in this section we further explore theories by carrying out indoor tests varying both positioning accuracy and target size. Again using the hopscotch layout we have carried out 64 tests with 20 participants of mixed age and gender. In these tests the participants were able to select the level of difficulty. This was varied using the target size as well as the accuracy of the positioning system. The accuracy was varied by adding random error values to the detected x:y coordinates (already with an inherent 5.7cm standard deviation). These values were scaled to achieve proximity to preset standard deviations. It is not possible to precisely achieve standard deviation figures as the values generated are random and within an unknown timeframe - the length of the game. The error distribution is also likely to be different to the distribution for the ultrasonic positioning system and hence a different value for k is predictable. The number of tests for each condition are shown in Table 2 with the number of unsuccessful, or timed out, tests shown in brackets.

Table 2 shows that none of the participants were able to complete the test with the target set to 10cm, and with the accuracy set to 2m the test could only be completed with a target size of 2m. With a time limit of 45 seconds for each movement between bases *no* participant was able to complete a test where the system accuracy approached the target size. By the time 45 seconds had elapsed we found that participants ceased to search effectively as they had either lost interest or they suspected that the task was impossible. In retrospect the time limit could have been set higher to further explore the condition where

Table 2. Accuracy Tests: Number of Participants per Condition. () indicate timeout.

Target Dia.	10cm	20cm	50cm	1m	2m
Accuracyσ					
10cm	(5)	3	3	1	2
20cm	(1)	2	10	5	1
50cm	-	(1)	4	13	2
1m	-	(1)	(3)	1	2
2m	(1)	(1)	(1)	(1)	1

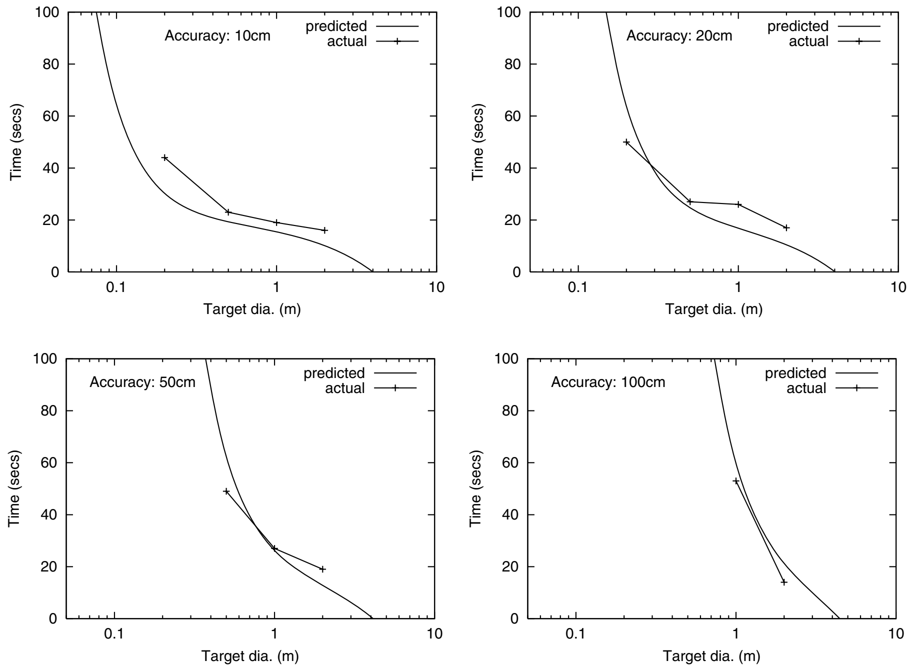

Fig. 6. Effect of Positioning System Accuracy

the target becomes relatively small; perhaps more active encouragement of the participants would have facilitated this. The self selection allowed the participants to choose settings which resulted in a satisfactory game and this is reflected in the distribution of conditions attempted.

The mean results are shown graphically for each accuracy setting in Figure 6, along with the predicted curves using a value of k=1.5. We applied regression theory to these curves firstly to assist in determining a suitable value for k, and secondly to evaluate the match of the data to Equation 3. The resulting values were 0.81, 0.65, 0.74 and 0.93 for increasing position error values, indicating fair to good matches.

The curves in Figure 6 indicate that, as a rule of thumb for this application, target locations should have a diameter of at least the size of 2 x standard deviation of the positioning system and at most a quarter of the distance between locations. (Note that in this application we have a generated a *normal* error distribution which may not be typical of such systems). These indoor test applications, however, are not typical and we thus carried out tests outdoors with a standard GPS receiver to provide additional support for the use of Equation 3.

4 Testing Outdoors

Due to the worldwide availability of GPS the majority of location-based applications are found outdoors. As outlined in the introduction, a wide range of location dependent digital information is becoming available ranging from tourist information to situated mediascapes. With this in mind we have designed a GPS application in which a user explores a pedestrianised city centre, surrounding the Bristol Millennium Square, and discovers soundtracks associated with the city and its features. Composer, Roger Mills, and artist, Annie Lovejoy, developed the conceptual mapping of audio content based on the physical attributes of the area. The goal was to reflect aspects of the city; pieces portraying multiculturism and history. Adhoc interviews were conducted in streets, cabs and shops, and a musical collaboration was also included. The user is guided from landmark to landmark using images shown on a PDA connected to a shoulder mounted GPS receiver. Five landmarks were chosen along a 250m trail with each landmark visible from the previous one and displayed in sequence on the PDA. For example see Figure 7. The soundtracks are triggered at each location using GPS data at 1Hz. As with the hopscotch game in our indoor trials, the user has to search for the media at each landmark. Once it has been found an image showing the next landmark is displayed. Again the users were shadowed by a researcher to resolve any misunderstandings, and to encourage continued searching where small target areas were used.

The times and paths between leaving each landmark and triggering the next sound file are recorded. The accuracy of the GPS receiver was determined from a 24 hour test in a fixed position with buildings, trees and a dummy head providing some occlusion of the satellite signals so as to simulate the application conditions. Tests were carried out using target location sizes with diameters of 2m, 4m, 10m, 20m, 40m and 100m. The tests carried out at 2m diameter resulted in the application timing out after three minutes searching and this condition was thus removed from our analyses. The remaining data was normalised by starting measurements at a distance of 80m from each target. The walking speed was

Fig. 7. iPAQ showing the next landmark

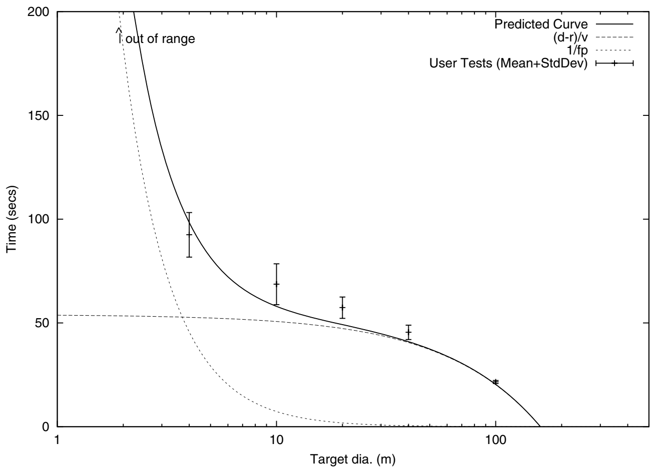

Fig. 8. Actual Task Times with Predicted Curve

determined by sampling along the route at points inbetween the landmarks where the users would not be carrying out any search.

Five sets of tests were thus initially carried out at 4m, 10m, 20m, 40m and 100m target diameter and analysed with our movement analysis equations. We plotted the results against Equation 3, and this is shown in Figure 8. A value of k=3 was used again with the GPS error distribution being similar to the indoor positioning system distribution. The dotted curves show the two main elements of the equation - the walking time to reach the target's boundary tapering off as the target radius approaches the distance to be travelled; and the search time ranging from infinity where the target is too small to be detected, to near zero where the target size is less than or equal to the area of uncertainty of the positioning system. Regression analysis was again applied yielding a correlation coefficient of 0.92 indicating a good fit.

The initial tests showed that for a target diameter equal to, or over 40m, the significant component was walking speed. At 5m diameter the uncertainty of the positioning system caused the search to become onerous for the users. Further experiments were thus limited to the 10m and 20m target diameter. A total of 19 subjects of mixed age and gender took part in the experiments: 10 subjects in the 20 metre diameter target size condition and nine in the 10 metre diameter target size. ANOVA resulted in a significant (between subjects) effect for target size, $F(1,17) = 5.49$, $p = 0.033$. There was no (within subjects) effect for targets and no significant interaction.

5 Discussion and Future Work

In the baseline tests we have carried out a study which indicates that a movement analysis is a useful method for the predicting the performance of a location-based application where a target is to be acquired. The correspondence of the data-points to the predicted curve along with regression analysis supported our theories where the target area is varied. However further work is required particularly where the target area is very small, and also where the times are short. We also did not investigate conditions at the target boundaries. A probabilistic approach may be more appropriate in these circumstances.

There were other elements of the baseline tests which are worthy of further discussion. The five different conditions were very different from each other in two respects. Firstly the p-values for each target size showed highly significant statistical differences from all the other sizes. There was not a particular reason to expect that this would be the case. After all the difference between 100 cm and 200 cm, or between 100 cm and 50 cm do not seem too different to expect such significantly different completion times.

The second way in which the sizes differed behaviourally was somewhat puzzling. Subjects did not perform consistently across the conditions, i.e. someone could be fast in the 100 cm condition but this did not mean they were also fast in the 50 cm condition. One possible cause could be the uniform distribution of the error introduced by the positioning system as this would not favour any particular subject. However, observing the subjects it seems that they adopted a particular strategy to deal with finding the target in a (possibly) varying world and carried on with this strategy, e.g. holding the handheld computer at a certain height, moving it about in a circular fashion to detect the target. For those ten subjects that started with the easier targets, however, there was a significant correlation between the first two easy conditions, i.e. those that were fast (or slow) in the 200 cm condition were also fast (or slow) in the 100 cm condition.

The accuracy tests in which both target size and positioning system accuracy were varied, also supported Equation 3, however there is a greater spread of data. This points to the limited sample we have gathered and again the probabilistic nature of this experiment. Equation 3 is not an absolute measure, it actually relates the probability distribution of the time required to complete the test to the probability distribution of the positioning system. Further examination of this aspect could be worthwhile but is beyond the scope of this paper. In particular, a comparison of the application of different measures of accuracy may be worthwhile. The adoption of, say, a 95% confidence level may be more appropriate than the use of standard deviation, and could make it possible to replace the error distribution factor k with a constant value.

The results from the GPS-based application illustrate the intuitively evident in a useful graphical form. Figure 8 appears to confirm the validity of our hypotheses, and is consistent with the authors' experiences of GPS-based systems. We can use this curve by applying, for example, 20% bounds to the optimum time. This then indicates that the preferred values of target location diameter, for our application, are between 6m and 25m .

It was evident that users adopted differing search strategies (with variable results) and an observational study could be productive into the effectiveness of these strategies. We have also assumed that users are aware of digital information being associated with known, visible, points. However if the points of association are not known, or not visible, to the user then it is likely that a systematic search strategy would be adopted e.g. 'lawnmowing'. The choice of search strategy, and relative merits of such strategies as applied to location-based applications, is a logical continuation of this research.

6 Conclusion

The approach which we have employed, demonstrates that it is possible to analyse the human aspects together with the design parameters associated with a location-based application. This gives a greater understanding of the factors which influence performance, and hence designers can usefully employ this approach to inform the design of future applications. The model that we have derived can be included in authoring packages for locative systems that are emerging at present [13, 14, 15]. These packages are designed to allow content designers to quickly deploy location-based applications. By incorporating our model, an authoring package could usefully warn designers when they create target zones that are too small, and thus hard to find, or too close to each other, causing ambiguous triggering of associated media.

We have thus presented a practical approach to reasoning about the relation between the time to complete a location-based task, a targeted location size and the accuracy of the sensed position. A formula has been proposed to describe this relationship, and shown by experiment that, for both an indoor gaming application and for an outdoor GPS application, there is a close correspondence between the formula and our measurements.

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