'LUCAS': The Library Assistant Robot, Implementation and Localisation

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Abstract

In modern ageing society, robots are been designed to play an increasing role in the lives of elderly people This paper describes a mobile robotic assistant, named 'LUCAS', Limerick University Computerised Assistive System, that is currently being developed to assist elderly individuals with mild cognitive or physical impairments within a library environment. The aim of the project is to provide an assistive socially interactive robotic aid. The main focus of this paper is on the localisation system of 'LUCAS'. A continuous localisation process is used which relies on monocular vision and ultrasonic range readings. The process employ's methods of straight-line-extraction, vanishing point estimation and ultrasonic pattern detection. The correspondence space is reduced by splitting the navigable space into localisation variant regions. The pose is calculated for each localisation hypothesis within the particular region and is used to correct the motion of the robot before it enters the next localisation region.

1. Introduction

Improving the quality of life for the elderly is an important goal for society today. According to the United Nations Population Division the number of elderly people is increasing dramatically in modern day society [1]. In conjunction with the increasing demographic trend, service robots are being introduced on a wide scale to maintain the well-being of the elderly population. This project particularly, but not exclusively, aims to cater for the social interactivity of the elderly. Social activities and contacts improve dependent elderly person's well-being. Dependent elderly people who are a member of a club, those who often meet their friends and relatives and those who often talk with their neighbours declare a higher satisfaction than the rest [2]. The types of robots used in assistance with the elderly population are being developed by several universities and research groups and vary greatly in their shape and form. PEARL is a robot that is situated in a home for the elderly and its functions include guiding users through their environment and reminding users about routine activities such as taking medicine etc. [3]. CARE-O-BOT is a robotic home assistant that can be used as an intelligent walking aid and also execute manipulation tasks [4].

An example of a place in society where elderly people may go, to interact with others or to participate in an activity is the local library. A library is an important location for the individuals to preserve their independence and social mannerisms. To contribute to this purpose the Biomedical Electronics Laboratory in the University of Limerick is developing a robot known as 'LUCAS': Limerick University Computerised Assistive System. 'LUCAS' is an autonomous library assistant robot that is used to assist individuals within the library environment while also socially interacting with them. The existing process in the college library to attain a specific book may be a time consuming and arduous process for elderly people or for people with various impairments. The aim of 'LUCAS' is to assist individuals with this manual task. The remainder of this paper is divided into four sections. Section II describes the task specific robot. Section III introduces the issue of localisation for an autonomous robot and describes the localisation process implemented for 'LUCAS'. Section IV presents the experimental results achieved and finally Section V concludes with a brief summary and future work implementations.

Proceedings of the 2005 International Conference on Computational Intelligence for Modelling, Control and Automation, and International Confe
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0-7695-2504-0/05 $20.00 © 2005 IEEE

2. 'LUCAS': The socially interactive robot

'LUCAS' is an autonomous agent 90cm in height, with a diameter of approximately 40cm. Fig. 1, shows a simplified diagram of the structure of 'LUCAS'. The structure of the robot is based on a custom-built platform, endowed with a differential drive system, encoders, bumpers, sonar-ring, monocular camera, Pyroelectric Infrared Ring (PIR) ring and on on-board central processing P.C. The structure allows for holonomic motion (ability to turn on the spot). Man/machine cooperation is essential in the creation of a successful assistant robot. A key difference between conventional and socially interactive robots is the way in which a human perceives the robot. DiSalvo et. al [5], stated that for a service robot to be successful the user must feel comfortable with the use of the robot and that human users prefer to interact with machines in the same manner that they interact with other people. An elderly person may be encouraged to interact with a robot if they can relate to the robots "personality" through its structural form and the cooperation between the robot and the user. To socially interact with its users 'LUCAS' uses a graphical interface rendering an animated 3-D human like character created by the CSLU toolkit [6]. The character has the ability to express emotions, communicate with a high level dialogue through a synthetic spoken voice system and displays visual text prompts. This system allows the elderly user to communicate with the robot in a natural manner. An interaction button incorporated into the robot's structure is used for simple user instruction clarification. Interactions with the robot occur when the user approaches a specific library catalogue computer. A graphical user interface (GUI) created in Microsoft's Visual Basic contains the existing library catalogue. The user may search the catalogue for the desired book. Interaction with the robot occurs when the user presses the 'robot' button inserted at the bottom of the GUI, which initiates a wireless Wifi network transaction of information on the chosen book between 'LUCAS' and the catalogue computer. Once 'LUCAS' receives information relating to the book it utilises a built in database created in Microsoft Access. Each book holds a corresponding geographical location coordinate in the form of (X, Y, Z). 'LUCAS' uses the X and Y information to determine the physical location of the book by implementing its path-planning algorithm (D*, [7]) with its priori map (grid based metric map). The 'Z' coordinate corresponds to the shelf number of the book's location. The robot reads the title of the book to the user, the user then confirms

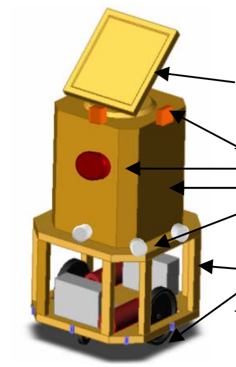

Fig. 1. Structure of 'LUCAS'

that it is the correct book by pressing the interaction button. 'LUCAS' then encourages the user to follow it to the location of the specific book via vocal dialogue and visual text prompts. Fig. 2 shows an example of the dialogue held once 'LUCAS' receives information concerning a library book selection:

3. Localisation process for 'LUCAS'

For a service robot to be successful it must have complete autonomous capabilities (planning, navigation and localisation). In this case autonomy refers to the ability to traverse the library environment, reach specific goal orientated goals, avoid obstacles within the dynamic environment and socially interacting with its user all without human intervention. It is assumed that the autonomy capabilities exist without the modification of the existing environment. The task of autonomy may be preserved if the issue of self localisation is maintained. In literature there are three main methods to solve the problem of localisation. The first is map-based approaches where the robot makes use of a user created geometric or topological model of the environment which is usually referred to as an "occupancy map".

[LUCAS]: Good Morning
[LUCAS]: The book you have selected is '*Title*' by '*Author*'
[LUCAS]: If this is the correct book please press the red button, if you would like to choose another book please return to the catalogue computer
……*wait for button press*…..
[LUCAS]: If you are ready to follow me to the location of the book please press the red button.
……*wait for button press*…..
[LUCAS]: Please follow me

Fig. 2. 'LUCAS' dialogue

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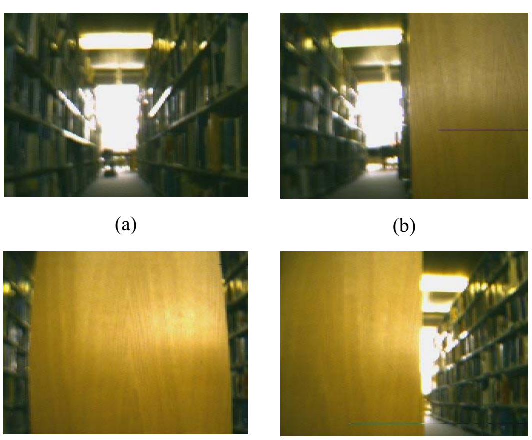
The second approach is map building based, where the robot uses its sensors to create geometric or topological models of the environment and then use these models for navigation. The third approach is map-less navigation; in which the robot has no explicit representation of the environment but relies on object recognition or object tracking to aid navigation. The most common approach for map-less navigation is navigation using optical flow. For indoor environments the map-based approach is the most common technique used due to the structured nature of the environment and is the method implemented for this project. To determine the robot's pose within the environment the robot must have the ability to accurately identify the landmarks (either natural or unnatural) within its surroundings. Several methods of landmark identification have been expressed in literature, with some of the most common methods involving the use of vision systems [8]. Stereo vision is popular for autonomous robot localisation since the environment may be described with 3-D information [9]. The main disadvantage of stereo vision systems is the complex computations resulting from two cameras. For low-cost implementation monocular vision systems are more desirable [10]. The localisation system presented here is a process where the robots configuration space is split into localisation variant regions. The robots position and orientation is updated from an initial starting position using basic odometry until a localisation variant region is reached. At each localisation region the robots pose is accurately updated using the localisation procedure for that particular region. Initially the robot's pose is determined with relation to environmental landmarks



(a) (b) (c) (d)

Fig. 3. Sequence of book-shelves

(rows of book-shelves); before it is updated to a world coordinate system. Before each positional movement is executed, sonar is used to ensure that the robot's immediate navigable space is unoccupied by unmapped dynamic obstacles. If an obstacle is detected, the D* algorithm is reiterated including the present obstacle and an alternative path to the goal is executed. The proposed environment is generally viewed as being parallelepiped in nature consisting primarily of rows of book-shelves. As the robot manoeuvres to its goal location, it passes a sequence of identifiable landmarks. Fig. 3, shows an example of the kind of sequence of book-shelves the robot would see as it traverses the library environment.

The localisation regions are determined primarily by the presence of dominant vertical lines within the image which determine the robots current position. The localisation method is a continuous process which initiates once the robot travels by the first shelf in the sequence of shelves indicated initially by odometry. Using the priori map the robot has a predefined definition of the location of the book-shelves. On each positional movement the robot identifies its position within the sequence of book-shelves and an image is obtained from the onboard camera. A classic four step approach is implemented for the image processing technique, 1: image acquisition, 2: image feature extraction, 3: feature manipulation and 4: camera pose computation. The camera used is a single monocular camera, the CMUcam2, created by Carnegie Mellon University, with resolution up to 352 x 288 pixels. The low resolution provides sufficient quality to extract the desired features while reducing the execution time of the image processing algorithms. Before information can be manipulated from the image, the image is first processed to enable high quality feature extraction. Firstly, the image is converted to a binary format using a high threshold; this is used to eliminate noise and unwanted detail in the image. An edge detection algorithm is implemented using the Sobel operator. The Sobel edge image is split into both vertical and non vertical (oblique) components. Once the image edges are obtained a simple connected component algorithm is used to form distinct line segments. This is a form of image segmentation where only the oblique and vertical lines of interest remain in the image. To simplify the processing technique lines that are less than a predefined threshold length of pixels are eliminated. After each positional movement the robot has a preconceived estimate of where it is positioned within the environment relative to the priori map due to odometry. This position estimation is prone to error especially due to drift and wheel slippage. To improve the position estimation the localisation algorithm, based on the number of extracted dominant lines within the processed image, is implemented after each navigational movement. Fig. 3, shows the different localisation regions present within the environment. In Fig. 3(a), no dominant vertical lines are present which leads to a localisation procedure implementing vanishing point estimation and ultrasonic pattern recognition. Fig. 3(b) and (d) show one dominant vertical line which implies that the robot is no longer adjacent the shelf edge as in Fig. 3(c), where two dominant vertical lines are present. In cases (b) – (d) the robots pose is determined by manipulating extracted features from the image and from ultrasonic range readings.

3.1. Robot's coordinate system

To localise the robot we need to define and evaluate three elements x_r, y_r and θ, which is known as the robot coordinate system and is centered at the projection center of the robot's camera. x_r and y_r correspond to the x and y location of the robot with respect to the priori world map with world coordinates X, Y and Z, whereas θ corresponds to the orientation of the robot. The x_r axis coincides with the optical axis of the camera and points towards the scene. The image plane is parallel to the (y_r, z_r) plane and displaced a distance f (focal length) along the x_r axis. Where the x_r axis pierces the image plane is known as the principal point and acts as the origin for the metric image plane coordinate system (x', y'). When the robot is locating the correct book-shelf row the direction of motion is along the Y axis. Once it has reached the correct row and is traversing the shelf aisle to locate the desired book the motion is now in the direction of the X axis. Fig. 4, shows the right-handed orthogonal coordinate system of the environment and the robot. When odometry determines the robot has reached the first row of book-shelves, the localisation process begins and an image is processed from the robot's current location. The complete localisation process is described by the localisation algorithm function below. If two dominant vertical lines are extracted as in Fig. 5(a), the y_r coordinate is known and as two ultrasonic sensors lie uniformly at either side of the camera x_r and θ, may be obtained using the ultrasonic readings. If only one vertical line is determined from the image as in Fig. 5(c), a second stage in the localisation process occurs. The position of the single dominant edge within the image provides essential information about

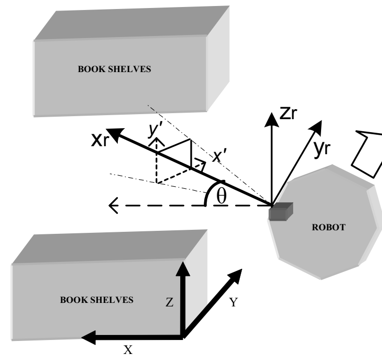


Fig. 4. Environment and robot coordinates

how far the robot is from the center aisle between the two rows of book-shelves. Using a procedure known as perspective projection which is approximated by the pinhole camera model, points in the image plane may be mapped to the object plane using simple geometry. A point *(u, v)* in the image plane may be mapped to the object plane with robot coordinate system by (1).

$$u = y_r \frac{f}{x_r}, v = z_r \frac{f}{x_r}. \qquad (1)$$

Using (1) the distance 'x' in Fig. 5(d) may be calculated, which is used to determine the y_r coordinate for the current position. The remaining coordinates x_r and θ may be established as before if the detected shelf edge lies within the overlap detection region of the adjacent ultrasonic sensors. Both ultrasonic sensors are arranged so that their combined field of view approximately equals the camera's field of view. As both sensor ranges are approximately the same the position of the shelf edge within the image allows us to determine whether the actual shelf edge lies in the field of view of both ultrasonic sensors. If both ultrasonic sensors can be used accurately x_r may be determined by the average of the two readings while θ may be calculated using the discrepancies between the two readings. If the shelf edge can only be measured by a single ultrasonic sensor accurately the orientation may not be determined until the next positional movement. If no dominant vertical lines are extracted from the image as in Fig. 5(c) a third stage in the localisation process is implemented utilising vanishing point detection and ultrasonic pattern recognition. This stage is implemented when the robot has reached the book-shelf aisle it needs to traverse to locate the specific book. With a pinhole perspective projection camera model, a set of parallel lines in 3-D space will converge to a single point on the image plane known as

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the vanishing point. In the case where an image is taken in-between the book-shelves (the aisle the robot has to travel down), each dominant oblique line, which corresponds to an individual book-shelf row, corresponds to a parallel line in the real world. Each row of shelves also lie parallel to each other, so the dominant oblique lines will all converge to a single vanishing point within the image. As vanishing points are invariant to translation and changes in orientation they may be used to determine the orientation of the robot. At this stage when the image is processed only dominant oblique lines are extracted as in Fig. 5(f). These dominant lines will converge to a single vanishing point which lies on the image plane. The longest dominant extracted oblique line is initially chosen to act as a central line and is intersected with each other line. This results in n different vanishing points where n is:

$$n = \sum_{i=0}^{i=nL} i \quad \text{where } nL \text{ is the number of extracted lines.}$$

The accuracy of the vanishing points depends on the accuracy of the two extracted lines used for intersection. A connected component algorithm is utilised, with vanishing points connected if they are within five pixels apart, which results in lists of vanishing points that are related. The list with the largest number of connected components is taken to calculate the exact location of the vanishing point. Using this method erroneous vanishing points are eliminated as error points will not have connected partners. If the maximum number of components in the selected list is not greater than three points, the intersection of lines is not strong enough and a second dominant line is chosen as a central one to intersect with each other line. This ensures that the central dominant line chosen was an accurately extracted line and will result in a correct vanishing point location. When a list of connected points is deemed suitable to correspond to an actual vanishing point, each point in the list is averaged resulting in an estimation of the actual vanishing point location (u_v, v_v) in image coordinates. To determine the orientation of the robot from the calculated vanishing point a method similar to that described by Jeon et al. is utilised [11]. Jeon's method of calculating the pose of the robot is implemented by referring to pre-recorded image sequences. The primary advantage of this method over Jeon's is that we do not use pre-recorded images so an image comparison technique is not required, thus improving the overall speed of the algorithm. Using this method the u coordinate of the vanishing point is

Function: Localisation Algorithm

```
1.  Image Capture
2.  Binary Thresholded Image
3.  Sobel Vertical Operator on Image (extract dominant vertical lines in image)
4.  Edgelink = {L1, L2 . . .Lk} where L is a line formed from connected edge points
5.  for i = 1 to k do
6.      if Li < max_length then
7.          delete Li
8.          k = k -1
9.      end if
10. end for
11. if k =2 then ( two dominant lines extracted from image)
12.     position_of_robot = adjacent book-shelf
13.     xr = μS1 + μS2 / 2 (μS1,μS2 = ultrasonic reading 1, 2)
14.     yr = Y location of book-shelf in priori map - error
15.     θr = tan^-1 (μS1 –  μS2 / 22cm)
16. else if k =1 then ( one dominant line extracted from image)
17.     position_of_robot = adjacent book-shelf + yr
18.     if position of k = left side of image then
19.         us_reading = μS1
20.     else if position of k = right side of image then
21.         us_reading = μS2
22.     end if
23.   overlap = overlap region of ultrasonic sensors at distance
                us_reading
24.     if position of k is within overlap then
        (both ultrasonic sensor readings may be used accurately)
25.     xr = μS1 + μS2/ 2
26.     yr = Y location of book-shelf in priori map +(position of k)
27.     θr = tan^-1 (μS1 – μS2/ 22cm)
28.     else if position of k  NOT within overlap then
        (both ultrasonic sensor readings may NOT be used accurately)
29.     xr = us_reading
30.     yr = Y location of book-shelf in priori map +(position of k)
31.     θr = unknown(may not be determined until next positional movement)
32.     end if
33. else if k =0 then ( zero dominant lines extracted from image)
34.     position_of_robot = inbetween book-shelves
35.     sobel horizontal operator on image
36.     execute lines (4)-(10)
37.     L = {Lmax, Lmax-1,….Lmin}
38.   (Lmax = largest line length, Lmin = shortest line length)
39.   vanishing_points() = L[1] intersected with L[2 to size of(L)]
40.   for i = 1 to  size of (L-1) do
41.         j = 1
42.     if vanishing_points(j) lies in the vicinity of
43.     vanishing_points(i) then
44.     group(j) = { vanishing_points(j), vanishing_points(i) }
45.     end if
46.         j = j +1
47.     end for
48.   vanishing_ point_selection = max(group)
      (group with largest number of connected points)
49.   calculate the mean location for the x and y coordinates of
      the points within vanishing_ point_selection for an
      estimation  of the location of  the calculated vanishing point
50. θr = tan^-1 (calculated vanishing point – correct vanishing
         point/f)
    (correct vanishing point  = location of vanishing point if
    there was no orientation error, f = focal length of camera)
    xr and yr determined when ultrasonic readings detect pattern
    when the robot is in-between the rows of book-shelves
51. end if
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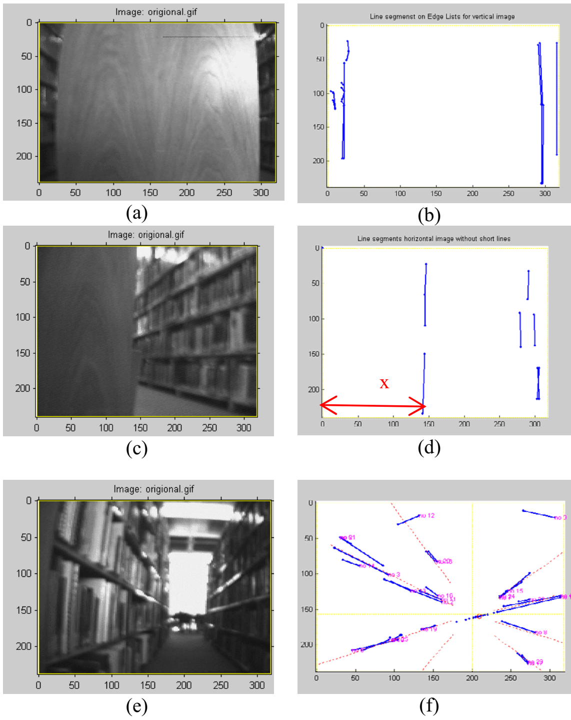

Figure 5: Various stages of the localisation procedure

used to determine the orientation of the robot using (2).

$$\theta = \tan^{-1} \frac{u}{f} \qquad (2)$$

For a more detailed explanation of (2) see [11]. At this point the robot uses the newly measured θ to turn to face into the book-shelf aisle it needs to traverse to locate the specific book. On entering the row of shelves containing the desired book, a unique ultrasonic pattern is searched for. Initially, when the robot is still facing into the book-shelves (but has not travelled in-between them) a sensor reading is taken form the suite of ultrasonic sensors (*p1*, Fig. 6). Ultrasonic sensor readings are taken periodically from the sensors every 500ms. The field of view of each sensor is projected onto a local occupancy grid as seen in Fig. 6. Once the robot enters in-between the rows of shelves a specific sensor reading pattern is searched for (*p2*, Fig. 6). Each sensor reading will change sequentially and uniformly on both sides on entering the aisle. Once the ultrasonic pattern has been determined the robot is said to be at the beginning of the aisle and the robots position with respect to the priori map is known. From this point as the robots position and orientation are known, odometry alone is

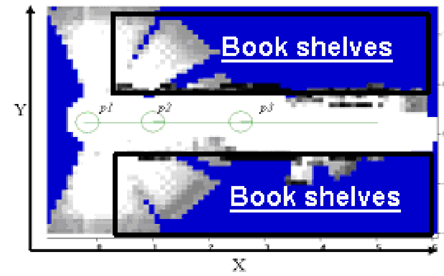

Fig. 6. Sonar readings as robot traverses aisle

used to traverse the remaining part of the aisle to locate the specific book. As the robot is traversing the aisle the ultrasonic readings are used to maintain the position of the robot within the center of the aisle (*p3*, Fig. 6).

Once the robot and reached the desired location and communicated with the user it returns to its home base location using a method similar to that previously described.

4. Experimental results

The above algorithm was implemented in the actual environment using real images and the results that were attained are described in the following section. Fig. 5 (a) shows the first image that was captured as the robot initialised the localisation process which contains two dominant vertical extracted lines. At this stage it was determined that the robot was situated adjacent to the book-shelf. The calculated robot coordinates x_r, y_r, and θ with respect to the position of the book-shelf were 69cm, -3.4cm and -0.78° respectively. The x_r coordinate was determined by averaging the values of the ultrasonic readings taken from the sensors adjacent to the camera and indicated how far the robot was from the book-shelf. Ideally, at this stage the two detected shelf edges should be centred within the image. The y_r coordinate is a measurement of the error of the positional movement. If y_r is a negative value the robot has travelled too far, if it is a positive value the robot has not travelled far enough so that the book-shelf will be centred within the image. y_r was calculated to be -3.4cm, which indicated that the robot has travelled too far and may be compensated for within the next position movement. θ was calculated to be -0.78° using basic geometry involving the ultrasonic range readings. Fig. 5(c) indicates the second step in the localisation process where only one dominant line was extracted. The extracted line was located in the left side of the image so the ultrasonic sensor located at the left side of the camera was used for the initial x_r coordinate. Using this initial measurement and the position of the extracted line within the image the overlap region of the two ultrasonic sensors was calculated and determined to be 71.6cm which was equivalent to 86.24 pixels centred in the middle of the image. The extracted line was situated within this region so the second ultrasonic sensor reading was used to accurately determine the coordinates. The x_r coordinate was calculated to be 75.9cm and θ, 21.35°. In this stage the 'x' distance in Fig. 5(d) is used to calculate the y_r coordinate. As before, ideally the robot should be adjacent to the shelf edge (two dominant vertical lines present) so y_r acts as an indicator of the error of the position movement. In this case 'x' was calculated to be 28.9cm. The shelf width is 50cm so y_r was determined to be -21.1cm. The final localisation stage is seen in Fig. 5(e), no dominant vertical lines were present so the vanishing point estimation was implemented. The intersection of the extracted oblique lines results in the dots present in the center of the image. The connected component algorithm was iterated which resulted in a vanishing point (circle in center of image) at location (208,153) in pixel coordinates, using (2), θ was calculated to be 7.42°. As the vanishing point was located to the right of the image the orientation of the robot was to the left. Once the orientation was established the robot turned to face the aisle and the ultrasonic readings indicated when it has entered the aisle. Table 1 shows the measured and calculated values at each localisation stage with the error value shown for each coordinate. As can be seen the error values are relatively small so the algorithm proved to be very suitable for navigation within this specific environment.

5. Conclusion

This paper provides a description of the design, structure and development of our service robot known as 'LUCAS' that assists elderly individuals with mild physical or cognitive impairments within a library environment. The main focus of the paper is on the localisation procedure used within the specific environment. The localisation method proposed here is a continuous localisation process rather than a single localisation step and results in fast low cost localisation within the specific indoor environment. As the localisation process is continuous odometry errors do not have time to accumulate, which implies that the initial position estimation using just basic odometry is relatively accurate. This allows the robot to apply the individual localisation procedure for each specific location based on odometry. The reduction in image processing techniques such as the use of a monocular vision system rather then a stereo vision system, straight line extraction and simplified vanishing point estimation result in a fast and very effective localisation system.

Table 1 : Results for each localisation stage

	Calculated x_r, y_r,θ	Measured x_r, y_r,θ	Error x_r, y_r,θ
Fig 5(a)	69cm,-3.4cm,-0.78°	68.7cm,-4cm,0°	0.3cm,0.6cm,0.78°
Fig.5(c)	75.5cm,-21.1cm,21.35°	74cm,18cm,20°	1.5cm,3.1cm,1.35°
Fig.5(d)	*,*,7.42°	*,*,6.15°	*,*,1.27°

- Ultrasonic sensors indicate when shelf aisle begins

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