Using a simple expert system to assist a powered wheelchair user

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Abstract. A simple expert system is described that helps wheelchair users to drive their wheelchairs. The expert system takes data in from sensors and a joystick, identifies obstacles and then recommends a safe route. Wheelchair users were timed while driving around a variety of routes and using a joystick controlling their wheelchair via the simple expert system. Ultrasonic sensors are used to detect the obstacles. The simple expert system performed better than other recently published systems. In more difficult situations, wheelchair drivers did better when there was help from a sensor system. Wheelchair users completed routes with the sensors and expert system and results are compared with the same users driving without any assistance. The new systems show a significant improvement.

Keywords: Expert system, driving, wheelchair, sensor, ultra-sonic.

1 Introduction

An expert system [1-8] is presented that improves the performance of a wheelchair fitted with ultrasonic sensors. The speed to complete progressively more complicated routes was recorded and results compared with recently published systems [9-13]. A significant improvement is demonstrated.

The simple expert systems described here allow a wheelchair user to drive their wheelchair faster when using them. Systems identify obstacles and suggest safe routes [14-21].

The human wheelchair user is often still a useful and reliable supply of information but that can be weakened by disabilities such as reduced vision. The expert systems overcome that limitation and improve the control of a wheelchair. The systems decode joystick data [17,22] and sensor data [23-25] and mix them [26,27].

2 Ultrasonic sensors

Ultrasonics were used because they are tough and uncomplicated [4,5,28,29].

Sanders *et al* presented the most recent ultra-sonic sensor system for a wheelchair [10-13]. The work described here uses the same chair (fig. 1) and the same sensors so that results can be easily and directly compared.

Fig. 1. Bobcat II Wheelchair

Three different operating modes could be selected:

- Joystick data sent directly to the controllers.
- Sensors activated and a computer modifies the direction of the wheelchair using recently published approaches.
- Sensors switched on and the computer modifies the direction of the wheelchair using the new expert system described here.

The following rules were applied:
- The wheelchair user stayed in overall control.
- Expert systems only change the direction when it is necessary.
- Turns to be controlled and smooth.

The ultrasonics could be noisy and there could be some misreads. Reliability was improved by filtering out misreads using Histogramic In-Motion Mapping. The volume ahead the sensors was split into grids of: adjacent, intermediate and furthest (fig. 2).

When an object was detected then it was classified as being adjacent, intermediate and furthest. More than one sensor was mounted in such a way that their beams overlapped ahead of the chair. An array of two sensors is represented in fig. 3.

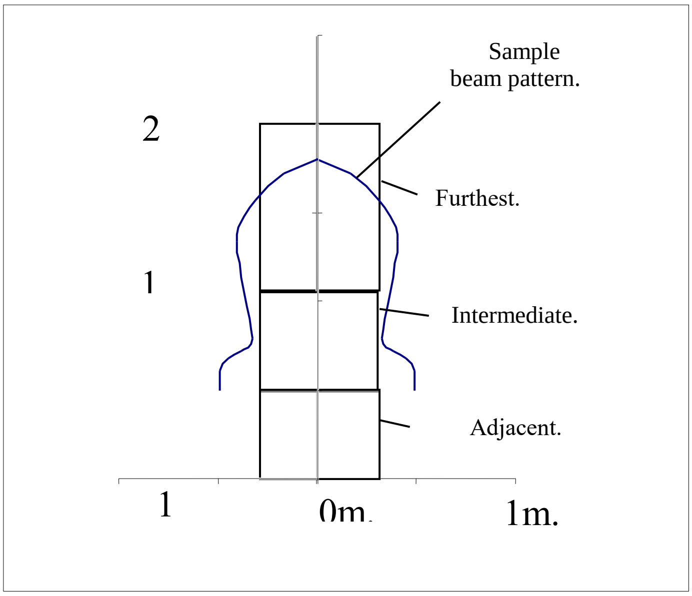

Fig. 2. The envelope for the ultrasonic transducers.

If an object was detected, then the array element or elements that represented the volume of the object is increased by a comparatively large amount (e.g: 5). The other cells in the array would be reduced by a smaller number (e.g: 2). Each array had a max amount of fifteen and a min amount of 0. Figure 4 represents a simple 3-element histogrammic depiction of the situation ahead of the wheelchair. The object in the 3rd cell caused that cell to increase quickly to max value. Misreads in any other element might temporarily increase that element, but false reads then reduce. If the object moved into another element, then the new element would quickly increase to max value and the previous element would then reduce.

3 Algorithms to interpret the joystick.

Joystick position was read by an ADC as Cartesian co-ordinates. They were transformed into polar co-ordinates $|J|\angle\theta$. Where $|J|$ represented how far a joystick had been moved, and $\angle\theta$ represented the angle.

Angular position was quantified to estimate the desired course. An algorithm measured how long a joystick position was maintained to show a particular direction so that the systems promptly identified the desire of the wheelchair users.

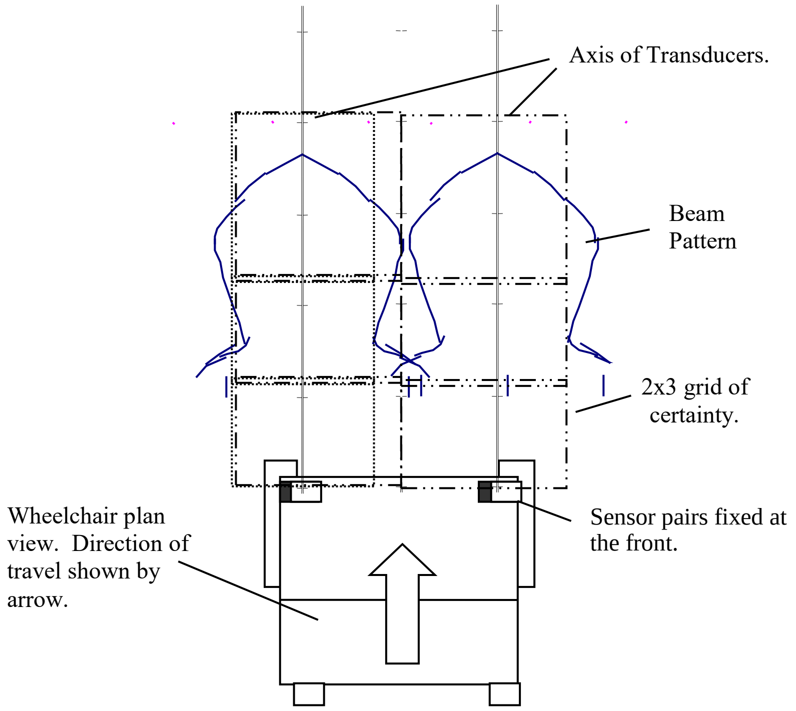

Fig. 3. Representation for a two-sensor array.

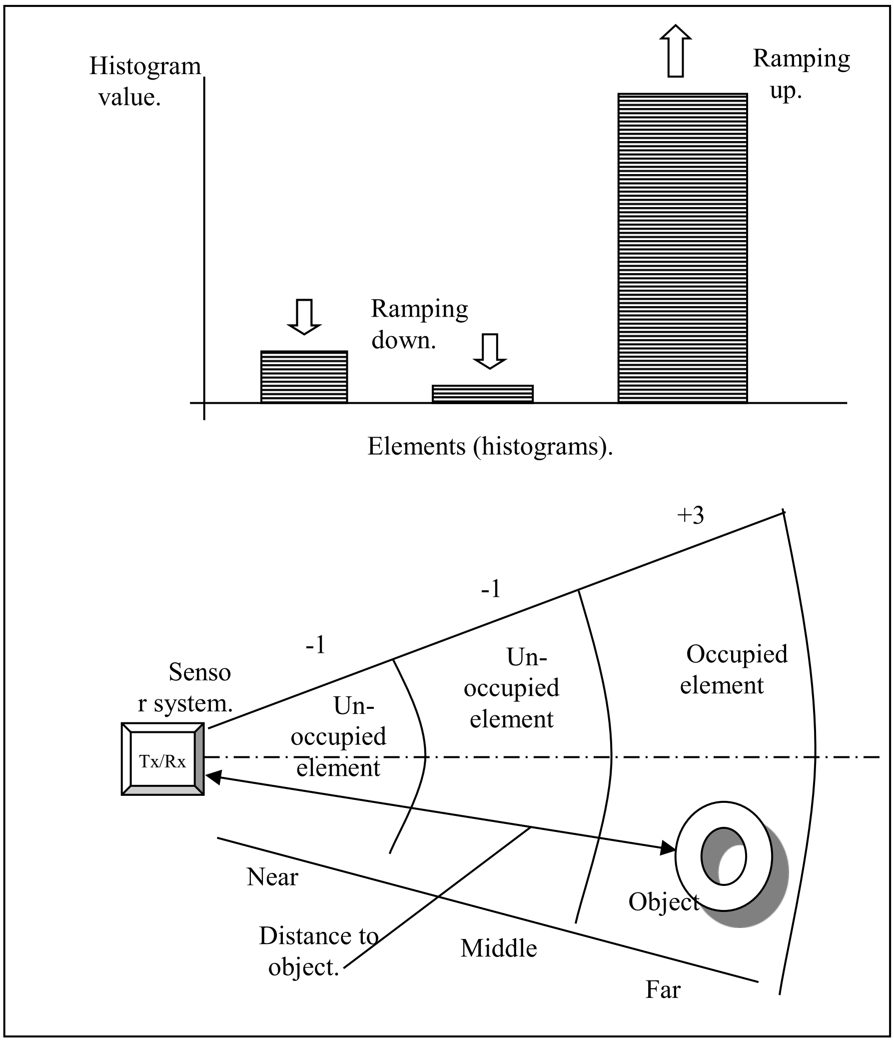

Fig. 4. A representation of the sensor histograms.

Angle and Magnitude were employed to evaluate the segment occupied by the joystick. Confidence was represented within a grid and each joystick cell in the grid held two figures:

- "Angle Confidence" (zero to fifteen).
- "Magnitude".

If a joystick was kept still, the grid segment representing that place increased in value. Other segments then reduced. An array segment with the biggest value was the most confident position for the joystick. Any random joystick movements might increment a segment briefly, but those false reads quickly reduce. Joystick position was represented as a histogram where the biggest histogram segment represented the most likely direction indicated for the user.

Histogram elements decayed quickly but built up more slowly. Delay and ramping weighting factors were found experimentally.

4 The simple expert system.

Some AI was introduced [30-47]. A modular structure was used to simplify writing and redcue code duplication [48,49]. The final structure was similar to a Blackboard type framework [1,7].

Experts provided expert knowledge [50-52]; in this case human wheelchair drivers. The system needed to operate in real-time. The user would indicate a direction and speed and the expert system gathered data concerning the environment. A high-level module called SensExpert analysed the sensor data and recommended a direction to avoid colliding with any obstacle. JoystickMon interpreted what the user needed to do. JoystickMon examined variables such as joystick consistency and position to understand the desired direction. JoystickMon could conflict with SensExpert. In that event, an expert called FuzzMix was responsible for the final controller outputs to the motors. The top level expert systems consisted of: FuzzMix, JoystickMon, SensExpert and Door. Door was the obstacle avoidance expert [54, 55] that could avoid obstacles using a "distance function". Door could adjust the direction generated by FuzzMix. The distance to an obstacle was measured by the ultrasonic transducers and the historical input from the joystick determined how the wheelchair should react. Door could turn the wheelchair away from the nearest obstacle, slow the chair smoothly as moved close to an obstacle and centralise the chair between obstacles, such as adoor frame.

FuzzMix coordinated the joystick and the sensors and allocated control to the sensors or the joystick. The instantaneous relationships at any time might be: all joystick but no sensors, all sensors but no joystick or something in between.

Distance functions were used to create values for right and left voltages.

A joystick plot was separated into sectors that can be used to identify joystick position. Sectors were: Forward, Turn left, Turn right, Spin left, Spin right, Back and Stop.

Factors that increased confidence in joystick position were:

Sensors agree with joystick,
Joystick staying in the same position,
Joystick position increased (working against the sensors).

Factors that decreased confidence in joystick position were:

Conflict between the sensors and the joystick,
Unsteady joystick position.

SensExpert decided whether to: Do Nothing, Stop, Turn right, Turn left, Slow, Spin left or Spin right.

Expert systems were downloaded to hardware on the powered wheelchair and then tested by driving the wheelchair.

If SensExpert and the joystick both indicated "forward" ten the system drove straight-ahead. Sensors still determined distances to obstacles and speed reduced if the chair came closer to an obstacle.

If necessary, SpinLeft and SpinRight commanded the wheelchair controller to turn. Observing experienced human drivers using a joystick with their wheelchairs, it was observed that they often moved their joystick using extravagant movements even when they were only performing a gentle manoeuvre.

5 Testing.

Systems were tested in corridors to check that SensExpert recommended safe changes in direction for the wheelchair. Tests then moved into laboratory and afterwards out into real environments. The wheelchair users rapidly learnt how to drive their wheelchair with the sensors and switches and to estimate stopping distances.

Tests compared speed with computer assistance with basic control without ay assistance in a set of specified and controlled environments. The system was observed when the wheelchair was controlled only by the human user and when being controlled jointly by the computer and the human user. Time taken was recorded for human wheelchair users by themselves without any help, and then again with assistance from the most recently published systems, and then again with the new systems.

Up to two groups of three tests (six tests) took place for each route. Two groups of tests took place without any automatic assistance or sensors. Then the tests were done again with assistance provided by the computer system and the original sensor systems engaged and finally tests were done for a third time using the new simple expert systems described here. The two groups of tests were:

- Driver just using the joystick.
- Driver wearing beer goggles.

A series of obstacles were set up in a different environment for each test. They were:

LAB – Open flat floor space with vertical walls and 2 x obstacles in a laboratory.

SIMPLE CORRIDORS – Open flat floors and some sloping floors. Vertical walls and some wide doorways. 3 x obstacles in a zigzag arrangement.

COMPLEX CORRIDORS - Open flat floors and some sloping floors. Vertical walls and some doorways. Some protruding radiators and door surrounds and some doorways. Several obstacles in zigzag arrangements.

OUTSIDE – More complicated location and surroundings with people walking around. Various flat and sloping floors and some sloping and vertical edges. Natural obstacles and extra objects placed there for testing.

Human drivers were variable, so tests were repeated so that users could learn about the systems and do their best. Testing was popular and fun, and volunteers tried to beat their best time and beat others. Tests started at constant pre-determined standing starts and time was measured with both a laboratory digital clock and a stopwatch and an average was taken between the two.

The scene from a camera mounted on the front of the wheelchair is shown in Fig. 5 in a complex corridor. A researcher followed the wheelchair with a stop watch and another researcher can be seen holding a laboratory clock at the end of the route.

Fig. 5. Wheelchair moving though a complex corridor viewed from a camera on the chair.

6 Results.

The wheelchairs safely moved around obstacles in a variety of set routes. The assistive systems automatically steered away from obstacles and avoided collisions.

Results in fig. 7 and fig. 8 show the new expert systems consistently performing faster than the most recently published systems or the human wheelchair users driving themselves. An exception was that on straightforward and uncomplicated routes, with wide gaps and only a few obstacles, then the human wheelchair users completed the routes more quickly when they did not have any assistance. This is shown in fig. 6 and fig. 7 in the bar charts to the left compared to those on the right.

Results was repeated whether a user was wearing beer goggles (fig. 7) or not (fig. 6). Human wheelchair users could drive their wheelchair quickly through wide gaps, perceive the situation and make adjustments, without any reduction in speed and without any need for help from sensors or the intelligent systems.

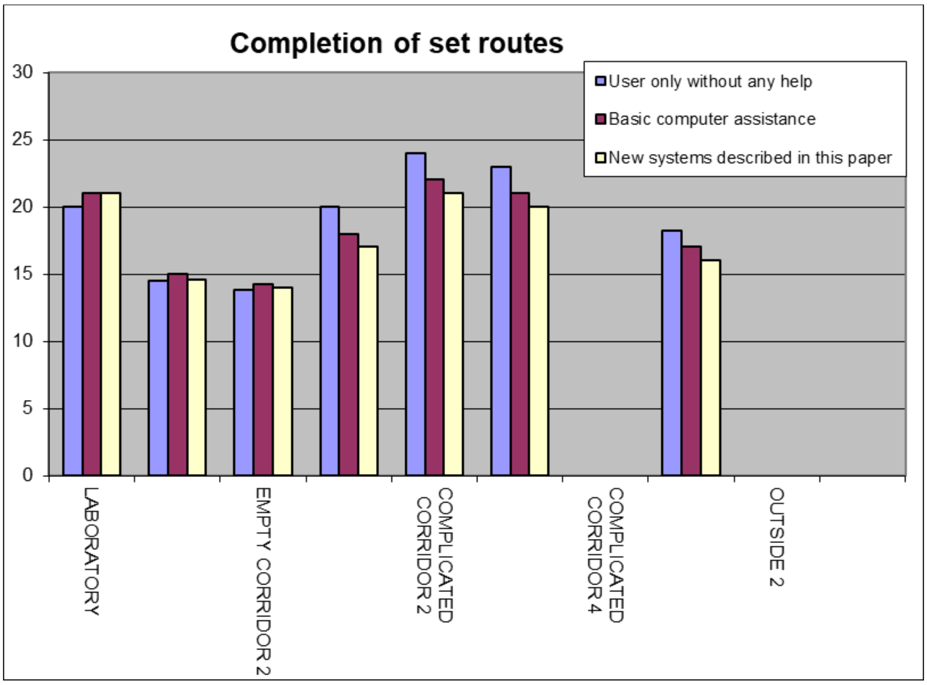

Fig. 6. Results from tests when the driver was not hindered.

As routes became more complicated or gaps were reduced then the human wheelchair users found it more challenging to estimate gap widths or to calculate a successful path for the wheelchair to safely pass through the gaps. Users had to slow the wheelchair or stop the wheelchair and then reverse to avoid collisions. As routes became more complicated, the humans performed better when they had some help from the computer systems and sensors. Users with assistance performed consistently better (faster) than previously published systems. Sensors were most useful on slopes, changing surfaces and when there were obstructions.

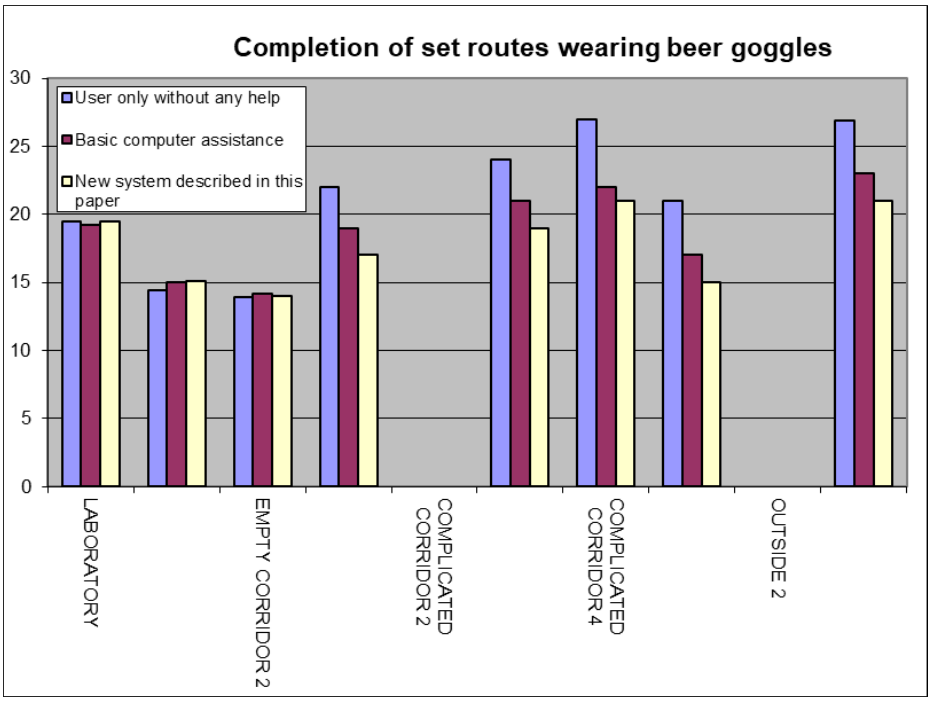

Fig. 7. Results from tests when the driver was wearing beer goggles.

When the human wheelchair users were wearing beer goggles then the results became even more pronounced. Humans performed best when they could see well. When vision was restricted then results were slower without assistance (as shown in fig. 7). When the users were assisted then the results improved but were still not as good because the wheelchair users had a tendency to be more careful.

Figures 8 to 16 compare results from unhindered drivers to drivers wearing beer goggles. Figure 8 shows a lab test.

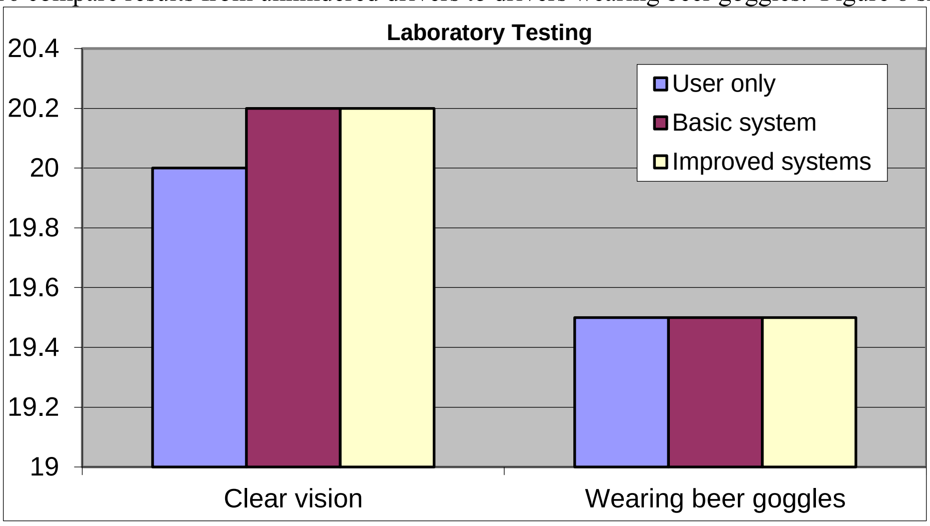

Fig. 8. Laboratory testing

Results from testing within an empty corridor are shown in Fig. 9. Wheelchair users completed the route more quickly without any help however when the new expert system was used (the right hand bar) then it functioned more effectively than the basic system published previously (middle bar). The form of results is repeated in fig, 10.

Results in fig. 11 change a little. If the systems help the users, then they consistently perform faster. The new systems are significantly faster.

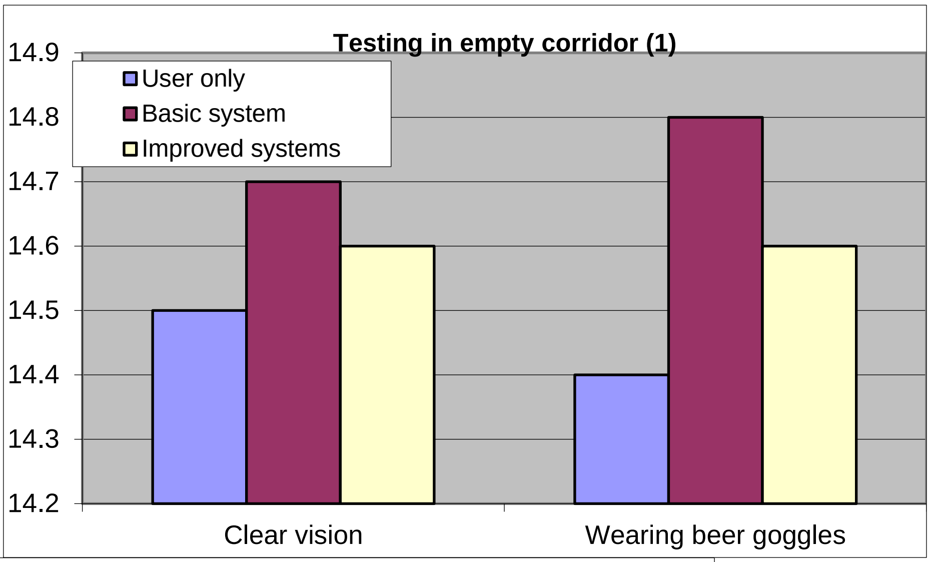

Fig. 9. Testing in empty corridor 1.

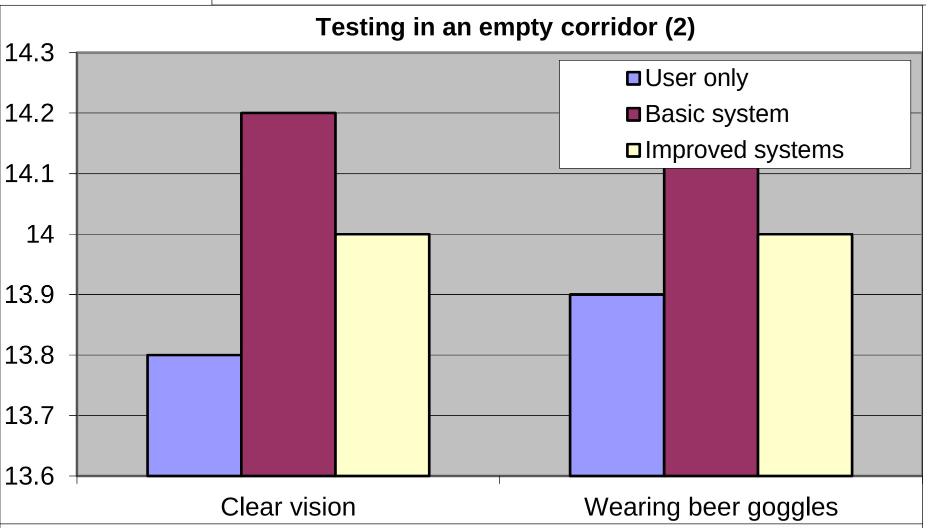

Fig. 20. Testing in empty corridor 2.

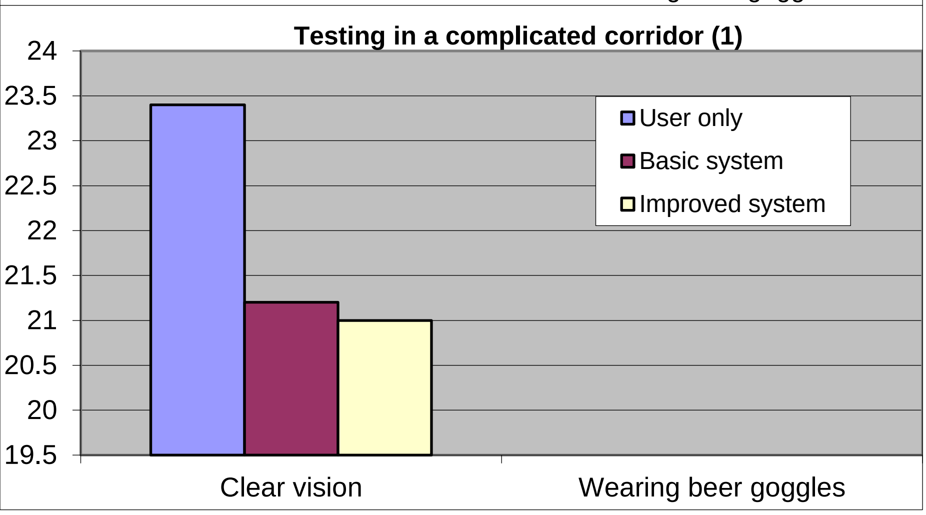

Fig. 31. Testing in complicated corridor 1.

That result is repeated in fig.12, There not enough results for statistical comparison when users were wearing beer goggles. Figure 12 shows results from a more complex route.

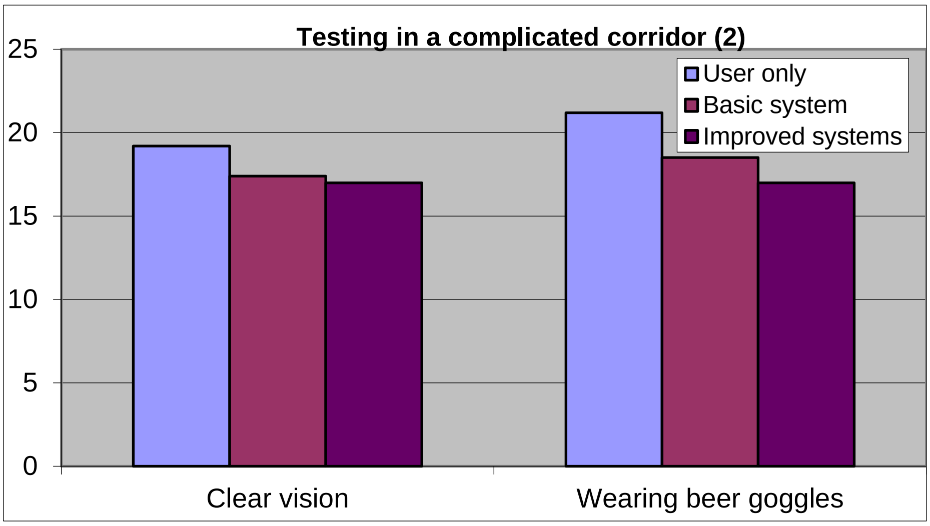

Fig. 42. Testing in complicated corridor 2.

The form of the results is repeated for more complex routes shown in fig. 13 and fig. 14. Differences are more pronounced for more complicated routes

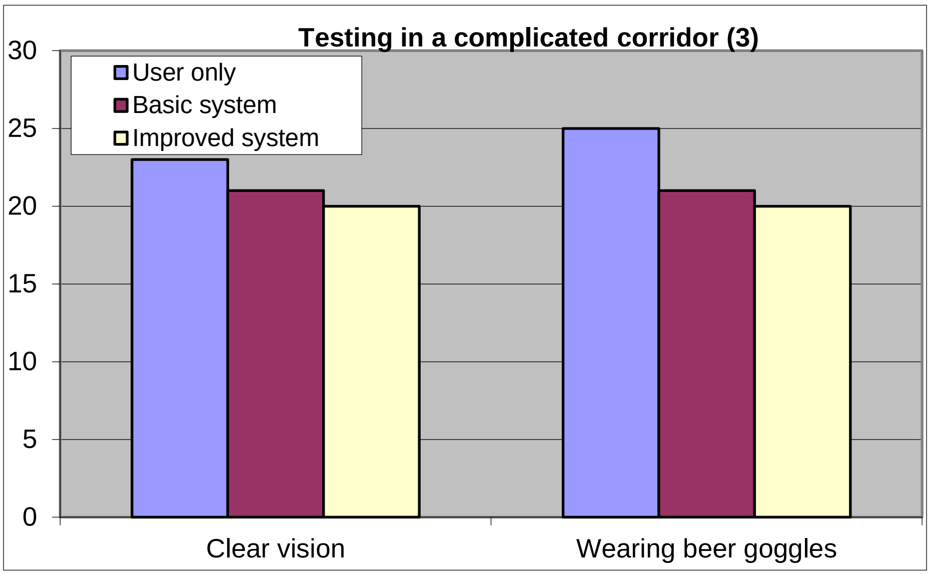

Fig. 53. Testing in complicated corridor 3

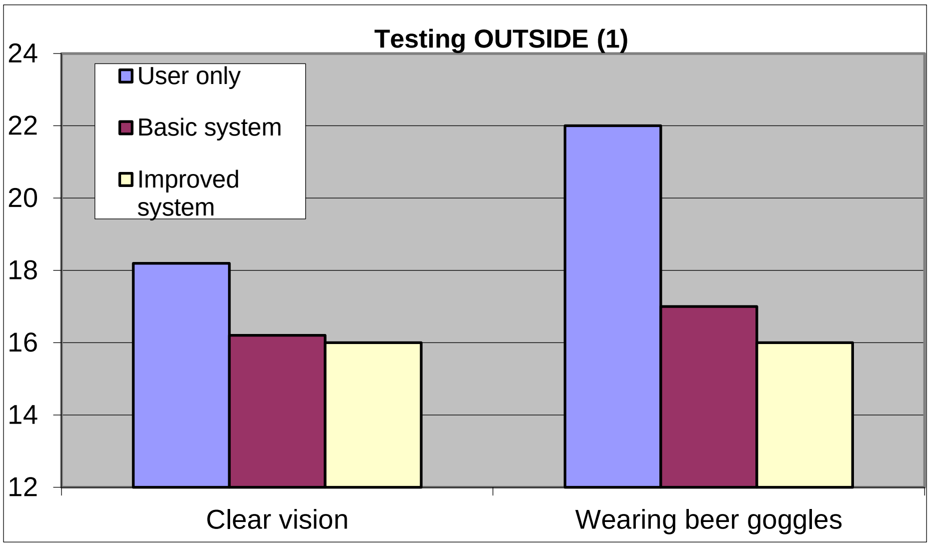

Fig. 64. Testing in complicated corridor 4

The form of the results is repeated for complicated outdoor routes as shown in fig. 15 and fig. 16.

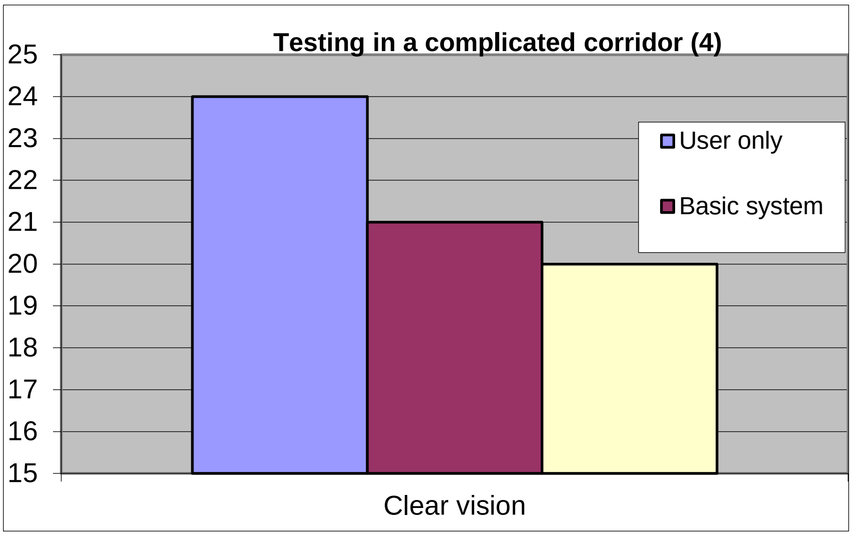

Fig. 75. Testing on outside route 1

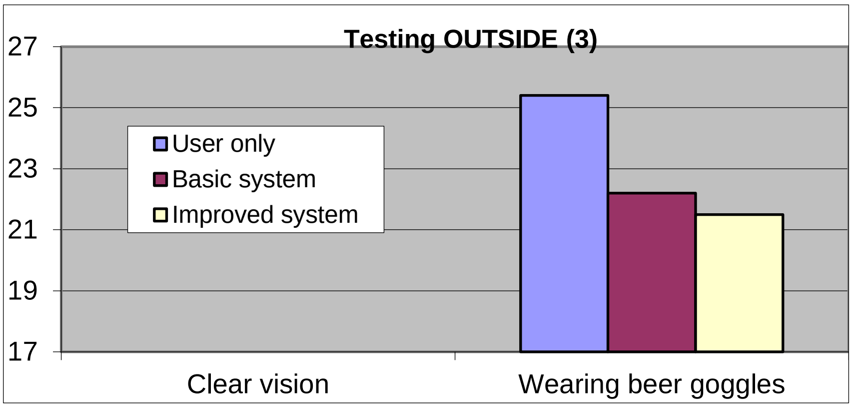

Fig. 86. Testing on outside route 3

7 Discussion and conclusions

Samples were compared using a t-test. The mean $\bar{x}$ was calculated for each sample with S2, variation or dispersion and S, standard deviation. These were used to calculate variance σ^2 and μ, the mean for the population. Caution was needed before the results could be generalised because the discrete sets of tests were not significant.

Results were arranged into pairs: with sensors helping and without sensors. Paired samples tests were used because people (the wheelchair users) are characteristically erratic. The pairing of the data removed a lot of that variation. Results were analysed and the paired-samples statistical test showed that wheelchair use without the sensors and computer system was significantly different to wheelchair users using the sensors and computer systems at $p < 0.05$ (95% probability).

On simple routes, users drove faster without sensors assisting them but as routes became more complex, wheelchair users drove faster and more safely with help. Human wheelchair users could not judge gap widths as accurately as the sensors and occasionally they found it challenging to direct their chair through gaps. Users often slowed their chair or stopped and reversed to avoid collision. The automatic systems never had to do that. On more complicated routes, users constantly did better with help from the systems. As gaps became narrower, the assistive systems consistently helped the users to perform faster.

Effects were more pronounced on more complicated routes when humans had their senses impaired by wearing beer goggles. If other people walked near to the wheelchairs and the sensors were not being used, then the human users tended to stop (and occasionally they aborted the test). When helped, then they had a tendency to keep driving as they would know that the wheelchair tended to move around people.

Future work will investigate virtual reality [56], time delays [57], wheelchair veer [58], web interfaces [59,60] force sensing [61], assessment using multi-media [62] Perception [63] and automation [64].

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