Selecting a best compromise direction for a powered wheelchair using PROMETHEE

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***Abstract*— Research is described that determines the direction that a powered wheelchair will take, using the Preference Ranking Organization METHod for Enrichment of Evaluations II (PROMETHEE II). This is the first time that this sort of decision making has been used in this type of application. A user suggests a desired direction and speed, and the decision-making system suggests a safe direction for a wheelchair. The two are mixed and the wheelchair then tends to avoid obstacles. The inputs come from a powered wheelchair joystick and two ultrasonic transducers fixed onto the wheelchair and the final direction is a mix of the desired direction and a direction that moves the wheelchair away from obstacles. The arrangement assists a disabled driver to steer their wheelchairs. It uses a systematic decision-making process and this paper presents the process and a new way of selecting a best compromise direction. Sensitivity analysis is employed to explore potentially suitable directions as uncertainty and risk may be present. A suitable direction is selected that provides a robust solution. The user is able to over-ride the suggestions by the PROMETHEE II system by holding the joystick in a position.**

***Index Terms*—Wheelchair; PROMETHEE, Disabled; Steer.**

I. INTRODUCTION

A multi criteria decision making (MCDM) system is described that assists in controlling powered wheelchairs. Some ultrasonic sensors deliver information concerning the surroundings of the wheelchair and that allows the system to assist a disabled driver with avoiding obstacles and obstructions. A human wheelchair user supplies a desired direction and a sensor system suggests a new direction. The final direction is an intelligent mixing of the two.

Around 7,000,000 people in America use some sort of assistive mobility device. According to Mobility Devices Statistics [1] roughly 2,000,000 people use a scooter, or a wheelchair and another 5,000,000 people use canes, walkers and crutches etc. About a third of the people who use an assistive mobility appliance need to be assisted by others. Stroke and osteoarthritis are principal primary disabilities for users of wheelchairs and scooters [2]. The principal condition associated with the use of mobility devices is osteoarthritis [1]. People who use powered wheelchairs often lack dexterity or mobility because of hand, arm, shoulder or more extensive incapacity, without sufficient lower limb force to move a manual chair [3]

Joysticks are often used to govern the speed and direction of powered wheelchairs. If a user cannot use their hands or fingers or is lacking in coordination then there are alternatives such as foot control, head or chin controllers or sip tubes/puff switches etc. If a wheelchair user lacks spacial awareness, has neurological or physiological problems or has a head injury, then they may not be competent to steer safely. Prospective users for the new types of wheelchair could be blind or not able to take avoiding action, etc. The systems that are described in this paper can help wheelchair drivers like these to steer their powered wheelchair in a safe way.

A wheelchairs controller is usually open-loop. A powered wheelchair driver indicates a preferred direction and speed by setting a transducer. That could be a joystick or a lever. Then the wheelchair will tend to move in the chosen direction and at the preferred speed. The user then makes necessary corrections to avoid any obstacles. In this paper, a method that processes the steering input and blends it with sensor inputs in a new way is described. The system assists a powered wheelchair driver to safely steer their wheelchair. A desired direction is combined with sensor information [4, 5 & 6] so that drivers receive assistance.

The navigation and steering of powered wheelchairs has been studied [7 & 8]. Procedures have normally been local, with little effort made make more global improvements. Researchers have considered how to avoid obstacles [9] using sensors provide more local inputs [10].

Researchers have considered the calculation of an initial path for a wheelchair that is then modified locally if any obstructions are perceived, but those systems have rarely been used to successfully help powered wheelchair users. The use of a Multi Criteria Decision Making (MCDM) system with sensors is described that can be successfully used to drive wheelchair motors. The resultant system can quickly react to obstacles ahead and will tend to turn towards a preferred direction while avoiding any obstacles.

Techniques are presented here that provide a best compromise direction for collision avoidance. A joystick controls the speed and direction and MCDM systems [11, 12 & 13] modify that control if required. The wishes of the user are traded against the distance from the wheelchair to nearby objects. A MCDM output determines a steering angle that can be combined with inputs from a joystick. The wheelchair motors are then driven by modified steering angles. The new procedures described here were simulated and then tested using sensors fixed onto a wheelchair, figure 1.

Fig. 1. The Bobcat 2 Powered Wheelchair used for the research.

The solid steel frame of the wheelchair base provides stability and strength. That base is enclosed within an outer fiberglass shell. The wheelchair has two big driving wheels at the front and casters trailing at the rear. Figure 1 clearly shows the two big driving-wheels. The large wheels were mounted on a common axis. Orientation / Direction and Motion were attained by independently driving each of the large wheels. To achieve this, each of the driving wheels had a separate motor connected to it to drive the wheel independently. In this way, the wheelchair users could steer their wheelchair by altering the current being sent to the motors.

Sanders et al. [14] described sensors that have assisted powered wheelchair users to avoid obstacles safely, for example using infrared sensors [15]; ultrasonics [16] and structured lighting [17]. Global systems have proved to be awkward within buildings [18] but more local sensing systems have been successfully used, for example: tilt sensors odometers, gyroscopes, or ultrasonics [19, 20 & 21]. The price of cameras is dropping, but processing can still be more complicated. The price of computers is also dropping, and they are becoming ever more powerful [20], so that cameras are being selected more frequently. All that said, a disabled wheelchair user still often provides the best information about what is needed, but their disability or reduced visibility might diminish their ability [22].

In th work described in this paper, ultrasonic sensors were used because of their robustness, low cost and simplicity [20]. The sensors are explained briefly in Section II and then Section III describes Multi Criteria Decision Making (MCDM). Section IV describes some of the tests conducted and the results recorded. Section V is a short discussion and Section VI presents some conclusions.

II. The Ultrasonic Sensors

The sensors were similar to those explained in [23]. They were attached to the bodywork on top of the driving wheels [24]. The distance to an object was calculated from the time for a pulse to be sent towards an object and then reflected back to one or both of the receivers [25].
Figure 2 illustrates the beams of the two ultrasonic sensors and the grid that can be produced.

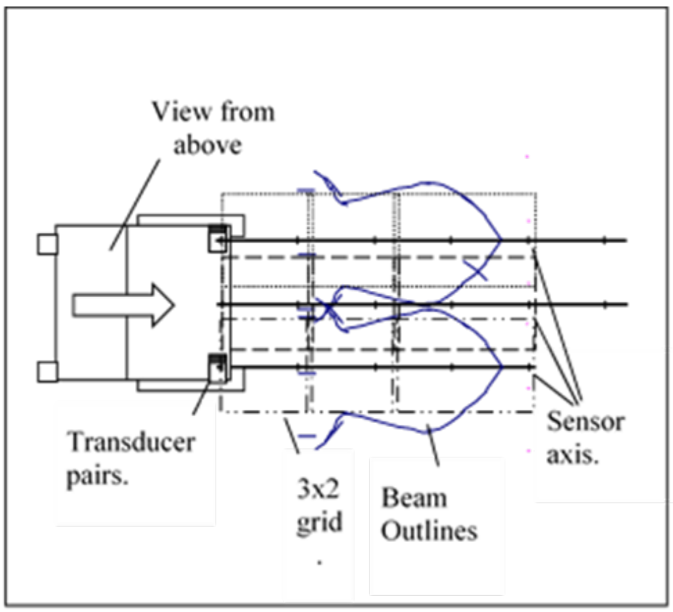

Fig. 2. Overlapping ultrasonic beam patterns can be used to create an array.

The system placed an imaginary potential field around any obstacle that was detected [16 & 26]. If no obstacles were being sensed, then the sensor range was increased by making the ultrasonic pulses longer until something was detected. In that way, a warning was given about any complications that might be forward of the wheelchair. Data within each of the ultrasonic range scans consisted of $(x,, \{r,\phi\}^{n}_{i=1})$, where r is the range, x, y, θ represents the pose at that moment in time, and ϕ is a simplified scan bearing (left, right, middle).

Histogramic In-Motion Mapping was used because ultrasonics can be noisy and give false readings [25]. A volume in front of the powered wheelchair was split into a left-hand and right-hand side (fig. 2). Each side then had a matrix over-laid on it with a volume in the center that overlapped. There were three elements within each matrix: ADJACENT, NEARBY and DISTANT.

Ultrasonic transducer beams over-lapped. The center column of the matrix represented conditions when both right and left transducers detected something. Any obstacle detected in front of the chair was labelled as ADJACENT, NEARBY or DISTANT.

III. Decision Making and PROMETHEE II

Multiple Criteria Decision Making (MCDM) is recognized as a significant branch of operational research and decision-making theory. MCDM was used to evaluate choices to select a suitable direction with regard to criteria that sometimes conflicted [27]. MCDM. It is a group of processes and methods through which contradictory criteria can be assimilated into a decision-making process. In addition, MCDM can be thought of as systematic and able to analyse and choose between various options. MCDM splits a problem into less significant chunks, analyses each chunk, and then aggregates the chunks to choose the best answer from a set of answers using predefined criteria. MCDM helps decision makers solve conflicting real-world multi-criteria problems, and to seek out a best-fit solution from a set of solutions within certain, fuzzy, uncertain, and risky situations [28]. This is the first time that MCDM has been used in a powered wheelchair application.

Durbach and Stewart [29] said that all multi-criteria methods can improve decision-making by deconstructing the assessment of the alternatives into the conflicting criteria. MCDM methods can be difficult to compare and to check their accuracy because they use a variety of methods to deal with different sets of data [30]. Razmak and Aouni [31] said that specific MCDM methods can work better for specific problems. Haddad [12] described steps to attain an appropriate compromise result for a problem with multiple criteria: Problem Identification; Goal and Target Definition; Criteria Definition; Identification of the alternatives; MCDM method selection to evaluate alternatives with respect to criteria; and Reassess and reevaluate the outcomes. The outcomes should then be reappraised and revalidated.

PROMETHEE methods are outranking MCDM methods with PROMETHEE I partial ranking and PROMETHEE II total ranking of alternatives. PROMETHEE methods generally consist of a preference function representing each criterion and weights describing their relative importance. The main idea of the PROMETHEE methods is to conduct pairwise comparisons among alternatives regarding each criterion then comprehensively compare them with respect to all criteria [32].

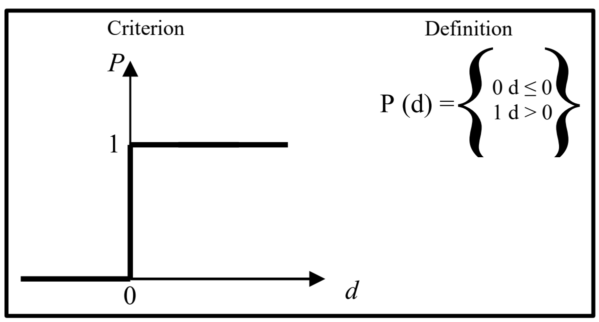

Fig 3: Selected preference function from Brans (1982)

Brans [33] identified six types of preference functions and the simplified function shown in Figure 3 was selected for this application. Moreover, Brans (1982) calculated Preference Indices using Equations (1) and (2):

Let $alt_a, alt_b \in A$ and:

$$\pi (alt_a, alt_b) = \Sigma_j P_j (alt_a, alt_b).w_j \quad (1)$$
$$\pi (alt_b, alt_a) = \Sigma_j P_j (alt_b, alt_a).w_j \quad (2)$$

Where, $\pi (alt_a, alt_b)$ expressed the degree by which alternative a was preferred to alternative b, and $\pi (alt_b, alt_a)$ expresses how much alternative b was preferred to alternative a.

And

$$\pi (alt_a, alt_a) = 0$$

$0 \le \pi\ (alt_a,alt_b) \le 1$

$0 \le \pi\ (alt_b,alt_a) \le 1$

$0 \le \pi\ (alt_a,alt_b) + \pi\ (alt_b,alt_a) \le 1$

$\pi\ (alt_a,alt_b) \approx 0$ weak global preference of a over b.

$\pi\ (alt_a,alt_b) \approx 1$ strong global preference of a over b.

And calculated the Positive, Negative and Net outranking flows using Equations (3), (4) and (5).

Positive outranking:

$$\Phi^{+}(alt_a) = 1/(n-1)\ \Sigma_{(x \in A)}[\pi\ (alt_a,x)] \quad (3)$$

Negative outranking:

$$\Phi^{-}(alt_a) = 1/(n-1)\ \Sigma_{(x \in A)}[\pi\ (x, alt_a)] \quad (4)$$

Net outranking flow:

$$\Phi\ (alt_a) = [\Phi^{+}(alt_a) + \Phi^{-}(alt_a)] \quad (5)$$

PROMETHEE methods don't produce a "correct" decision, rather they help a decision maker to find an option that matches their aim as well as their perception of the problem. This is the first time that this sort of decision making has been used in this sort of application and the next section describes the application.

IV. TESTING

This research used sensor inputs as decision criteria, which was the distance from the wheelchair to an obstacle. The inputs to the MCDM were: Distance from obstacle to the centre of the wheelchair (D_c), Distance from obstacle to the left of the wheelchair (D_l) and Distance from obstacle to the right of the wheelchair (D_r). If the sensors did not detect any obstacles in their range then the distance was set to DISTANT. Three scenarios are presented here as examples of the powered wheelchair moving through an environment containing some cardboard boxes as obstacles.

- Scenario 1: No obstacle detected (Position A in fig. 4).
- Scenario 2: Obstacle detected to the right or left (B in fig 4).
- Scenario 3: Obstacle detected to the left and obstacle detected in front (C in fig 4).

Three alternatives were considered based on the sensors' readings: Move left, move right and move forward. Scores for each alternative were set and are shown as a decision matrix in table 1.

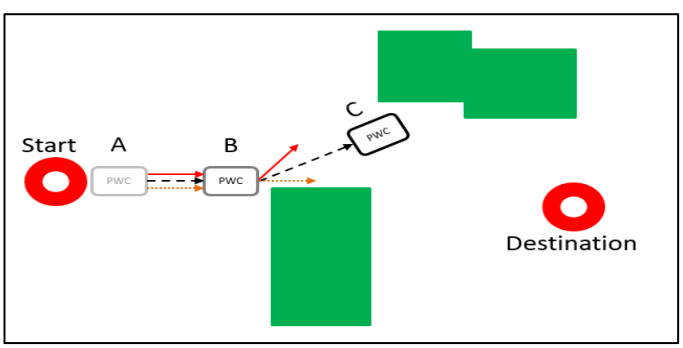

Fig. 4. Powered wheelchair moving through an environment containing some cardboard boxes as obstacles.

Table 1: Decision matrix for powered wheelchair

Criteria / Alternative	D_l	D_c	D_r
Move left (A_1)	0.5	0.25	0.167
Move forward (A_2)	0.333	0.5	0.333
Move right (A_3)	0.167	0.25	0.5

Dl, Dc and Dr could be ADJACENT, NEARBY or DISTANT. The values allocated to them were: ADACENT = 2, NEARBY = 4 and DISTANT = 10.

Scenario 1 (Position A in figure 4): As the wheelchair began to move, no obstacle was in the sensors range and all distances were set to DISTANT. PROMETHEE II was applied were three criteria and three alternatives were considered, all criteria had the same weight and were set to DISTANT. PROMETHEE II provided the following ranking of alternatives: $A_2 > A_1 = A_3$.The net outranking flow of alternatives were: A_1= 0.333, A_2 = - 0.167 and A_3 = - 0.167. The Geometrical Analysis for Interactive Assistance (GAIA) plan is a visual interactive module that provided a graphical representation of the PROMETHEE II method. It was used to provide a direction for the wheelchair, shown as a thick red line in figure 5 and as a solid red line in figure 4. That is to follow the direction indicated by the wheelchair user.

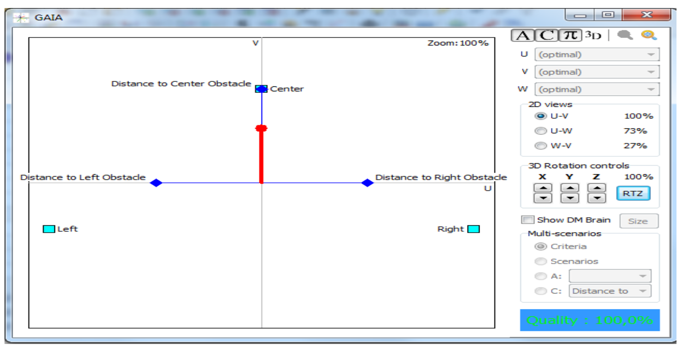

Fig 5: Suggested direction for the Wheelchair using PROMETHEE II, no obstacles detected.

Sensitivity analysis was conducted on criteria weights to analyze the stability of the outcome when uncertainty could affect the readings of the sensors. Minimum percentage change required to alter the outcome was calculated. Results are shown in table 2. N/F shown in Table 2 stands for a non-feasible value where ±100% change in the weight of that criterion did not affect the outcome of the method.

Table 2: Smallest change in criteria weights to change the outcome, scenario 1, no obstacle detected

Criterion name	Minimum percentage change
D_l	± 3 %
D_c	N/F
D_r	± 3 %

Figures 6 shows the effect of a 3 % change in D_l or D_r on the direction for the wheelchair. A 3 % increase in D_l or a 3 % decrease in D_r suggested that the wheelchair move forward with a slight angle to the left as shown in figure 6.

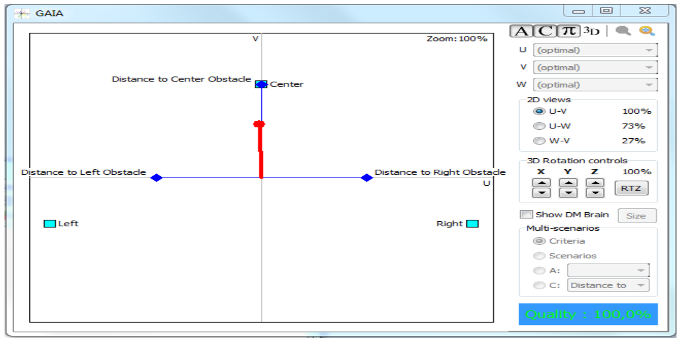

Fig 6: Suggested direction for the wheelchair with 3 % increase in D_l or 3 % decrease in D_r

A 3 % decrease in D_l or a 3 % increase in D_r suggested that the wheelchair move forward with a slight angle to the right.

Scenario 2 (Position B in figure 4): As the wheelchair moved forward then an obstacle was detected to the right of the wheelchair as shown in figure 4: D_r was set to ADJACENT, D_c was set NEARBY, and D_l was set to DISTANT. PROMETHEE II was applied were three criteria and three alternatives were considered. PROMETHEE II provided the following ranking of alternatives: $A_1 > A_2 > A_3$. The net outranking flow of alternatives was: A_1= 0.375, A_2 = 0.25 and A_3 = - 0.625. The GAIA plan provided the suggested direction for the wheelchair and is shown as a thick red line in figure 7 and as a solid red line in figure 4.

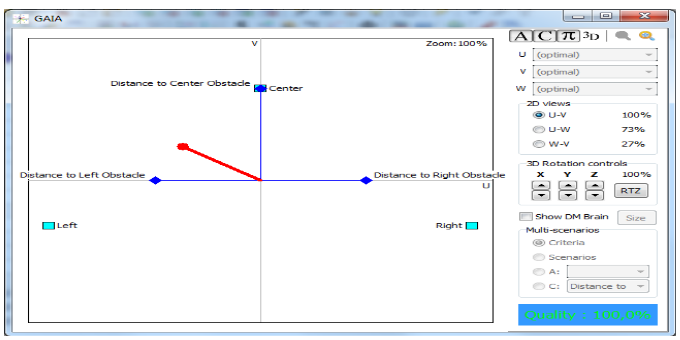

Fig 7: Suggested direction for the Wheelchair using PROMETHEE II, obstacle detected to the right.

Sensitivity analysis was applied to the criteria weights to analyze the stability of the result. The smallest percentage change that was needed to change the outcome was calculated. Table 3 shows the results.

Figure 8 shows the effect of minimum percentage change in Dl, Dc and Dr on the suggested direction of the wheelchair. An 8.065 % decrease in D_l, a 24 % increase in D_c or a 91.667 % increase in D_r made the wheelchair move forward and to the left with an angle of 134^o.

Table 3: The smallest percentage change needed in a criteria weight to alter the outcome, scenario 2, one obstacle detected to the right

Criterion name	Minimum percentage change
D_l	-8.065 %
D_c	24 %
D_r	91.667 %

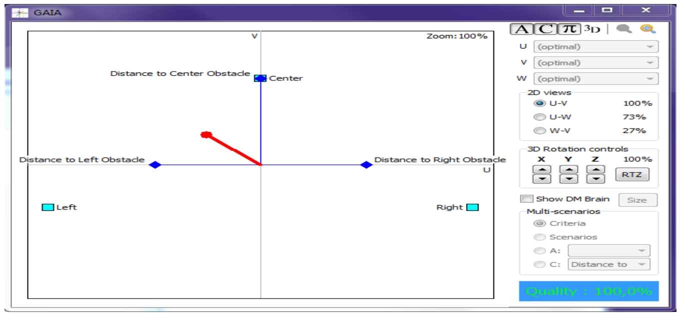

Fig 8: Suggested direction for the wheelchair of 134ºafter an 8.065 % decrease in D_l, 24 % increase in D_c or 91.667 % increase in D_r

Scenario 3 (Position C in fig.9): As the wheelchair moved forward then the system detected something on the left and something else was detected ahead of the wheelchair as shown in fig.9. D_r was set to DISTANT, D_c was set to NEARBY, and D_l was set to ADJACENT. PROMETHEE II was applied and three criteria and three alternatives were considered.

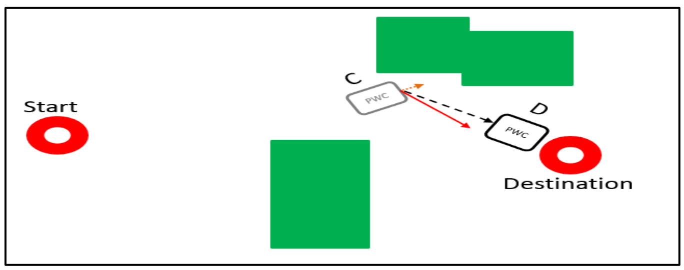

Fig 9: One obstacle detected to the left and another obstacle detected to the front.

PROMETHEE II produced the following ranking: $A_3 > A_2 > A_1$. The net outranking flow of alternatives was: A_1= - 0.625, A_2 = 0.25 and A_3 = 0.325. The GAIA plan provided the suggested direction for the wheelchair shown as a thick red line in figure 10.

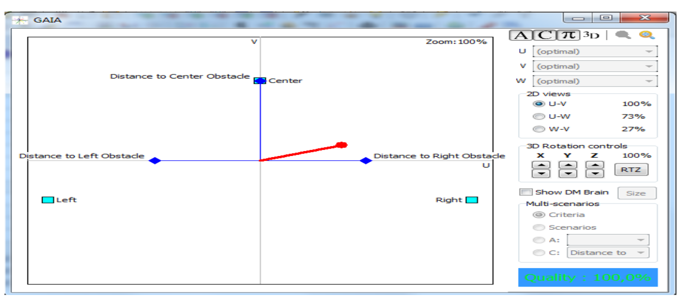

Fig 10: Suggested direction for the Wheelchair using PROMETHEE II, with two obstacles detected to the left and centre.

Sensitivity analysis was conducted on criteria weights to analyze the stability of the result. The smallest percentage change that would alter the outcome was computed and the result is shown in table 5.

Table 5: Smallest percentage change in criteria weights needed to alter the outcome, scenario 3, two obstacles were detected to the left and the center

Criterion name	Minimum percentage change
D_l	164.286 %
D_c	121.429 %

D_r	-22.535 %

Figure 11 shows the effect of minimum percentage change in D_l, D_c and D_r on the direction for the wheelchair. A 164.286 % increase in D_l, a 121.429 % increase in D_c or a 22.535 % decrease in D_r made the wheelchair move forward to the right with an angle of 46^o.

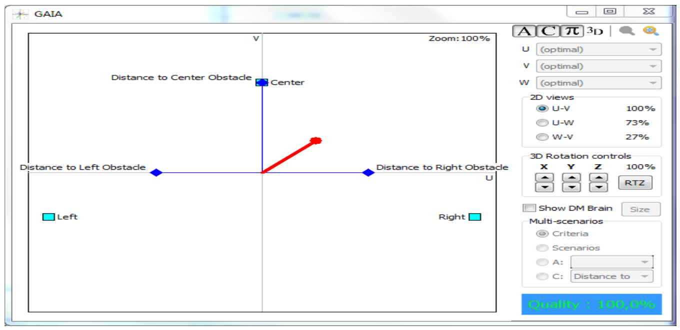

Fig 11: Suggested direction for the wheelchair was 46^oafter a 164.286 % increase in D_l, 121.429 % increase in D_c or 22.535 % decrease in D_r.

V. DISCUSSION

In this work, a joystick was used to provide the interface between the user and powered wheelchair to control direction and speed. The shared-control described in this paper combined suggestions form sensors and the input form the wheelchair driver and improved driving by reducing collision. Disabled drivers could often use their skill to safely control their wheelchair, but the sensors tended to be more accurate and repeatable and compensated for any lack of ability, awareness, or misunderstanding. This research combines autonomy and human driving skill with system intervention if needed. When a wheelchair user moved through complicated or varying environments then the sensors tended to provide better decision-making and decisions about directions to take.

The architecture described in this paper successfully combined the information from a user joystick in order to uphold the autonomy of the driver but also successfully shared that information with data form the sensor system. The wheelchair users successfully controlled the motion of their powered wheelchairs using their joysticks and the sensor system dealt with avoiding obstacles. The sensors ensured that the wheelchair was safe as it moved.

The actual currents driving the two wheelchair motors were produced by both the sensor system and the driver. If there were fewer obstacles or obstacle(s) were further away, then drivers didn't need assistance. Providing the driver with a higher authority in those cases guaranteed an improvement in performance. If the environment contained many obstacles or there were obstacles near to the powered wheelchair, then the system was able to inhibit or reduce the input from the joystick to prevent collisions.

The combined-control output was a summation of the weighted command from the driver and the output from the MCDM system. The resultant control command, Ccomd was:

$$C_{comd} = G_h\left|J\right| + k_t.C_{sens} \qquad (6)$$

Where $G_h\left|J\right|$ was the motion command from the joystick, C_{sens} was the output from the MCDM system and k_t was a constant that increased over time so that a user could always overrule the MCDM.

Figure 12 shows the resultant output when mixing PROMETHEE II with no obstacle detected and the joystick output when it was held to the right. The bold red line is the output from the MCDM system, the dotted orange line is the output from the user joystick and the dashed black line is the resultant actual speed and direction.

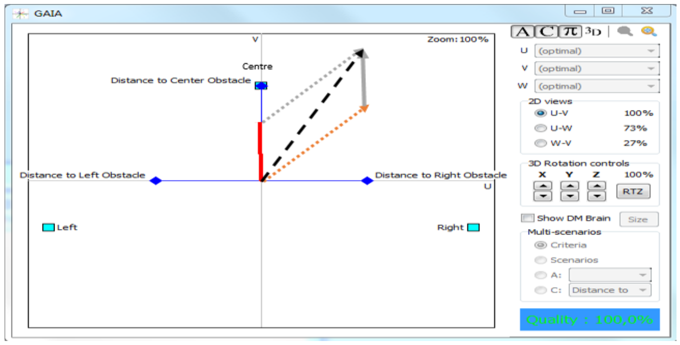

Fig. 12: Direction of the Wheelchair after mixing: PROMETHEE II output with no obstacle detected, 3 % increase in D_l or 3 % decrease in D_r and joystick was held to the right.

Figure 13 shows the direction of the Wheelchair when no obstacle was detected, and the joystick output was asking the wheelchair to move slowly to the right.

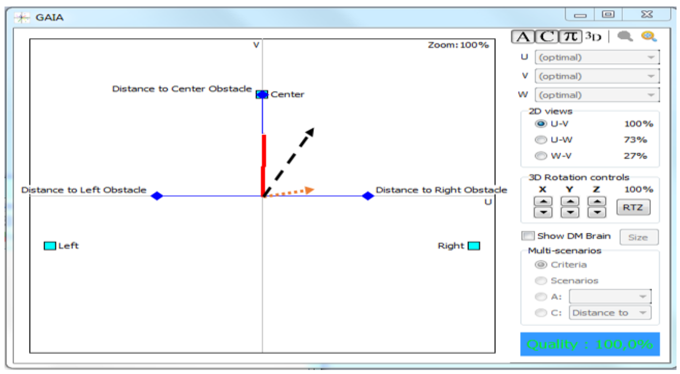

Fig. 13: Direction of the Wheelchair after mixing: PROMETHEE II output with no obstacle detected with 3 % decrease in D_l or 3 % increase in D_r and joystick output pushed a little to the right.

Figure 14 shows the direction for the Wheelchair when an obstacle was detected to the right, and the joystick output was asking the wheelchair to move forward.

Figure 15 shows the suggested direction for the Wheelchair when an obstacle was detected to the left, and the joystick output was asking the wheelchair to move slowly to the right.

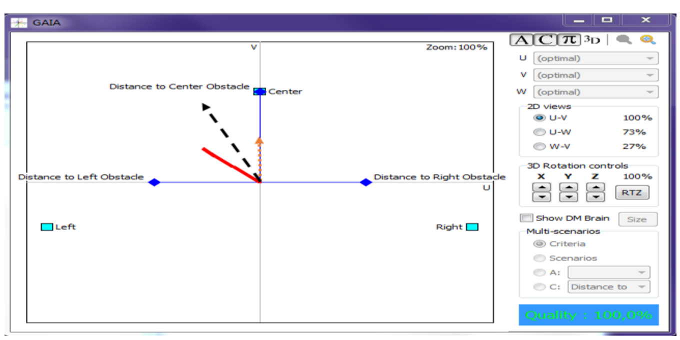

Fig. 14: Direction of the Wheelchair after mixing: PROMETHEE II output with an obstacle detected to the right, with an 8.065 % decrease in D_l, 24 % increase in D_c or 91.667 % increase in D_r and joystick was pushed forward.

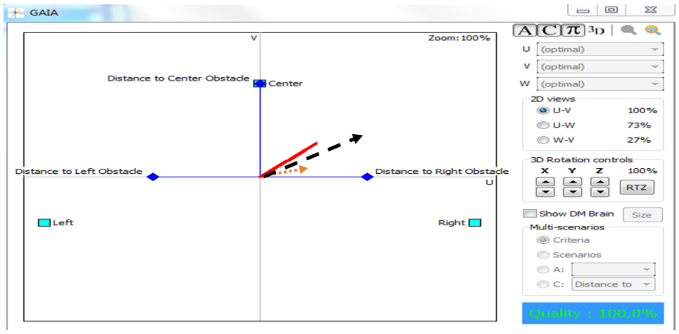

Fig. 15: Direction of the Wheelchair after mixing: PROMETHEE II output with an obstacle detected to the left with a 91.667 % increase in D_l, 24 % increase in D_c or 8.065 % decrease in D_r and joystick was pushed a little to the right.

VI. CONCLUSIONS

This paper described the successful use of a PROMETHEE II outranking method for collision avoidance in wheelchairs. The MCDM system was robust, safe, effective and straightforward. Powered wheelchair users were assisted with steering their wheelchairs as the system quickly detected obstacles and helped the users to steer safely around them.

The work can introduce some autonomy and reduce the need for carers by introducing simple and cheap AI software.

A limitation was that the MCDM rules are hard-coded and cannot learn. The research is now moving on to investigate ways that the system can learn more by combining different AI methods [2, 5, 24 & 34]. The idea will be that different AI methods can be are used to their best advantage.

A problem with MCDM was that not all situations could be considered during programming so that neuro, neuro-fuzzy or reinforcement learning might provide better solutions. Goal-based behaviours could be more efficient so in the future, they will be investigated along with the other AI techniques.

The MCDM would attempt to avoid obstacles but if a wheelchair user persistently indicated that they wanted to steer towards an obstacle (for example to turn on a switch) then the wheelchair user can over-ride the MCDM. The collision avoidance MCDM system could be over-ridden if a joystick was held still then the joystick output was integrated so that the disabled user would eventually over-ride the system.

The chair would tend to drive as directed by the joystick if no objects were being detected.

The authors are currently applying the Analytical Hierarchy Process and PROMETHEE II to other decisions. A framework for the intelligent selection of MCDM methods has been created [13] and analysing the behaviour of three MCDM methods in the presence of uncertainty has been investigated [35]. Veto threshold will be imposed and it will override the function of the joystick in extreme cases.

Other types of preference functions proposed by Brans [33] will be considered to provide a smoother and more efficient movement for the wheelchair and preference and indifference thresholds will be imposed to add stability. Future work will consider larger number of alternatives to cover 360^o around the powered wheelchair and uncertainty in inputs will be modelled using fuzzy set theory, percentages and probability functions. Monte Carlo simulation and other approaches will also be used to model uncertainty in more than one input factor at the same time.

The authors will consider the application of PROMETHEE VI (a representation of the Human Mind) which might provide better outcomes than PROMETHEE II along with GAIA plan to provide the direction and the speed of the wheelchair. The angle of the thick red line might be used to show the direction of the wheelchair (as used in the paper) and the magnitude of the thick red line could be used to show the speed of the wheelchair.

Results from testing the MCDM system showed that it behaved appropriately. The work will be clinically trialled in Chailey Heritage Foundation next year as part of an ERSPC funded project “Using artificial intelligence to share control of a powered-wheelchair between a wheelchair user and an intelligent sensor system." [26].

The research is now investigating the modification of pre-planned paths [36], force sensing [37] and comparing performance with and without the sensor system [38].

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