ADAPTIVE CONTROL BY NEURO-FUZZY SYSTEM OF AN OMNI-DIRECTIONAL WHEELCHAIR USING A TOUCH PANEL AS HUMAN-FRIENDLY INTERFACE

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Abstract: For improving the operability of an omni-directional wheelchair provided with a power assist system, the system must be able to adapt to the individual characteristics of the many different attendants that will use it. For achieving this purpose, an innovative human-interface using a touch panel that provides easy input and feedback information in real time of the operation of a power-assisted wheelchair was developed. The system was tested experimentally with many different attendants and the results show that in addition to providing a human friendly interface by using the touch panel system with monitor it can adapt successfully to the particular habits of the attendants.

1 INTRODUCTION

In order to satisfy the demand for higher mobility, designers have created new driving concepts such as omni-directional movement which allows any combination of forward, sideways, and rotational movement, thus ensuring users much more freedom and safety in wide or narrow spaces. A variety of wheelchairs with different options and special add-on features have been developed to meet a wide range of needs (Wada and Asada, 1999)-(West and Asada, 1992).

In the author's laboratory, a holonomic Omni-directional Wheelchair (OMW) which can act as an autonomous (Kitagawa et al., 2002) or semi-autonomous (Kitagawa et al., 2001) omni-directional wheelchair has been developed. Comfort has been a subject of study in the case with and without the joystick (Kitagawa et al., 2002), (Terashima et al., 2004).

For handicapped people or elderly people that can use their arms freely, many power assisted wheelchairs have been developed such as Seki (Seki et al., 2005) and Frank Mobility Systems (FrankMobilitySystems, 2002), for example. However, it is necessary to consider that some elderly people or handicapped people can not use their arms because they are damaged or they are so weak. These people needs the help of an attendant. Considering this background, a power assist system that helps attendants to move a heavy load has been designed and developed in author's laboratory (Kitagawa et al., 2004). Application of power assist for supporting the attendant of an omni-directional wheelchair is one of a novel research. To the authors knowledge, no other report about this topic has appeared yet. However, there is some research about power system for omni-directional vehicles, but it is related to *carts* (Maeda et al., 2000), *not to wheelchairs*. Moreover, it still has some problems in rotation and in occupant's comfort since this system was developed for a food tray carry vehicle in a hospital.

However, there is a problem related to the operability of the OMW. Due to the application of the power assist system, operability of the OMW degrades, especially when the attendant tries to rotate in clockwise (CW), or counter-clockwise (CCW) direction around the center of gravity (***CG***) of the OMW. This problem is generated from the fact that it is difficult to give the human force exactly towards the target direction by means of the handle attached to the wheelchair, hence the movement of the OMW using conventional power assist does not provide to the target exactly. Further-

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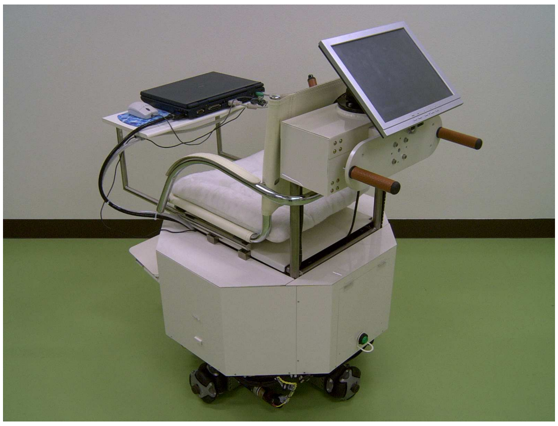


Figure 1: Omni-directional wheelchair (OMW).

more, the sensor position to measure the force added by human for power assist is different from the position of the gravity center of the OMW, and therefore the force generated by its difference must be compensated.

It was impossible to find general rules to solve the both problems stated in the above, but the relationship was found by authors between lateral and rotational movements. These relationships were used as the base for constructing a fuzzy reasoning system that helped to improve the operability of the OMW.

Nevertheless, when the system was tested by different attendants, it was found that a complete satisfactory result was not obtained by every attendant. It is because each person has its own tendencies and the fuzzy inference system must be tuned to respond to them. Tuning of the fuzzy inference system by trial and error thus has been tried by authors' group. However it is a time consuming and needs a lot of trials of the attendants, then these can become tired and bored.

Thus, a better tuning method, a method that allows tuning of the fuzzy inference system, is needed. It can be obtained by adding Neural Networks (NN) to the fuzzy inference system, obtaining what is known as a neuro-fuzzy system. There is a lot of research in this topic (Jang, 1993)-(Lin and Lee, 1991), being the basic difference the kind of NN that is used in combination with the fuzzy inference system.

Jang (Jang, 1993) developed ANFIS: Adaptive-Network-based Fuzzy Inference Systems, a neuro-fuzzy system in which the fuzzy inference system is tuned by using the input data of the system.

The desired direction of motion of the attendant as the teaching reference for the learning could be input by just using the keyboard of the computer. However keyboard input is not user-freindly. Furthermore, this method does not provide feedback information to the attendant in order to know how well he is accomplishing the desired motion. Then, a human interface that provides information to the attendant is desired. This can be achieved by using a touch panel system with monitor, which is a device that can be used as an input and at the same time can show the resultant motion of the OMW. The desired motion and the real motion of the OMW are compared in order to obtain the difference, or error, that will be used for the training of ANFIS, as explained in a previous paper (Terashima et al., 2006).

In a previous paper (Terashima et al., 2006) by the authors, the forwards-bacwards velocity was not included in the ANFIS system of the OMW and then a Reduction Multiplicative Factor (RMF) was used for the improvement of the rotational motion of the OMW when there was some interference of the forwards-backwards velocity. By using the RMF it was possible to achieve good operability in the forwards-backwards motion, lateral motion and rotational motion. However the results were not satisfactory in the case of slanting motion. By including the forwards-backwards velocity in the ANFIS system as shown in Fig. 6, and with the use of the touch panel for providing teaching reference for the learning, it was possible to acomplish a general omni-directional motion. Simulation and experimental results in the case of diagonal motion are shown in Fig. 13 and Fig. 14.

Hence, in this paper, an innovative method for improving the operability of a power assist omni-directional wheelchair by using a touch panel with neuro-fuzzy controller as a human interface is proposed.

2 CONSTRUCTION OF OMW USING A TOUCH PANEL AS HUMAN INTERFACE

A holonomic omni-directional wheelchair (OMW) using omni-wheels has been built by authors' gropup, as is described in (Kitagawa et al., 2002)-(Kitagawa et al., 2001). Figure 1 shows an overview of the OMW developein by authors' group.

The OMW is able to move in any arbitrary direction without changing the direction of the wheels. In this system, four omni-directional wheels are individually and simply driven by four motors. Each wheel has passively driven free rollers at their circumference. The wheel that rolls perpendicularly to the direction of movement does not stop its movement because of the passively driven free rollers. These wheels thus allow movement that is holonomic and omni-directional.

The OMW is also equipped with a handle and a six-axis force sensor, as shown in Fig. 1, that allows the OMW's use in power-assist mode. The force that the

Figure 2: Touch panel used for the OMW.

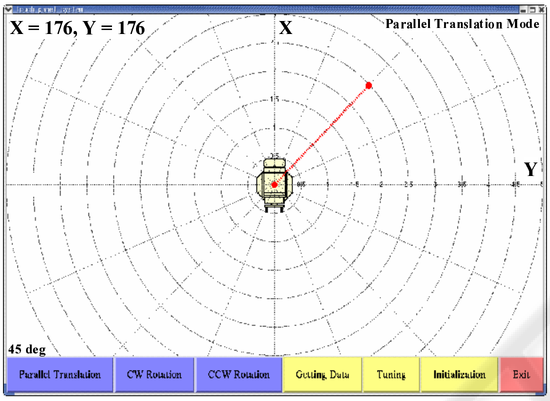
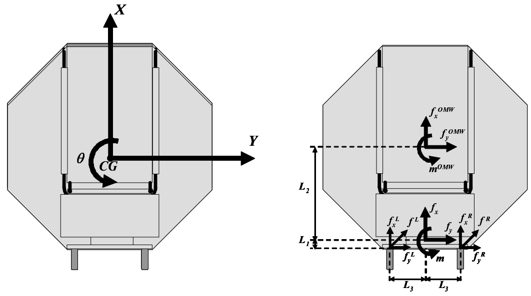


Figure 3: GUI developed for the touch panel.

attendant inputs to the grips of the handle is measured by this force sensor. Second order lag filter is used for the transformation from force to velocity (Terashima et al., 2006).

A touch panel is a display device that accepts user input by means of a touch sensitive screen. Because of their compact nature and ease-of-use, touch panels are typically deployed for user interfaces in automation systems, such as high-end residential and industrial control. Touch panels are also becoming common on portable computers such as Tablet PCs, Ultra-Mobile PCs and consumer devices such as VOIP phones. In this research, a touch panel as shown in Fig. 2 is used as an input device in which the attendant of the OMW draws the desired direction of motion. As shown in Fig. 2, the touch panel is mounted in the rear part of the OMW such as the attendant can reach to it easily. The touch panel used in this research is a TFT Touch Monitor HV-141T produced by ULTEC Corporation, Japan. A GUI (Graphical User Interface) was developed for making easy the interaction with the attendant, as show in Fig. 3. In this GUI the attendant can draw any kind of motion, be it an



(a) Coordinate system of the OMW. (b) Decomposition of the forces applied to the handles of the OMW.

Figure 4: Working force.

Table 1: Fuzzy reasoning rules for lateral motion and rotational motion.

R		Antecedent	Consequent
1	If	$Vy < 0$ and $\omega < 0$,	then $\omega < 0$
2	If	$Vy \approx 0$ and $\omega < 0$,	then $\omega < 0$
3	If	$Vy > 0$ and $\omega < 0$,	then $Vy > 0$
4	If	$Vy < 0$ and $\omega \approx 0$,	then $Vy < 0$
5	If	$Vy \approx 0$ and $\omega \approx 0$,	then 0
6	If	$Vy > 0$ and $\omega \approx 0$,	then $Vy > 0$
7	If	$Vy < 0$ and $\omega > 0$,	then $Vy < 0$
8	If	$Vy \approx 0$ and $\omega > 0$,	then $\omega > 0$
9	If	$Vy > 0$ and $\omega > 0$,	then $\omega > 0$

slanting motion, or a rotational movement.

3 NEURO-FUZZY SYSTEM FOR IMPROVING OPERABILITY

When the user tries to rotate OMW around its gravity center, OMW begins to slide and the radius of rotation sometimes becomes very big. Then, rotation around the center is very difficult (Kitagawa et al., 2004). A survey was conducted among various attendants trying to discover some relationships in the way they realized forwards-backwards, lateral and rotational movements. The goal of the survey was to find general rules that related the three mentioned motions. Even when it was impossible to find general rules that explained all cases, a relationship was found between lateral and rotational movements by authors. These relationships were used as the base for constructing a fuzzy reasoning system (MathWorks, 2002)-(Harris et al., 1993) that helped to improve the operability of the OMW. In order to establish the rules of direction inference, first, the force applied to the grips of the force sensor are changed to the center of OMW, as shown in Fig. 4. It is easy to derive a ba-

Table 2: Fuzzy rules for the change of Vx in order to improve operability.

R	Antecedent	Consequent
1	If $Vx < 0$ and $Vy < 0$,	then $Vx < 0$
2	If $Vx \approx 0$ and $Vy < 0$,	then $Vx \approx 0$
3	If $Vx > 0$ and $Vy < 0$,	then $Vx > 0$
4	If $Vx < 0$ and $Vy \approx 0$,	then $Vx < 0$
5	If $Vx \approx 0$ and $Vy \approx 0$,	then 0
6	If $Vx > 0$ and $Vy \approx 0$,	then $Vx > 0$
7	If $Vx < 0$ and $Vy > 0$,	then $Vx < 0$
8	If $Vx \approx 0$ and $Vy > 0$,	then $Vx \approx 0$
9	If $Vx > 0$ and $Vy > 0$,	then $Vx > 0$

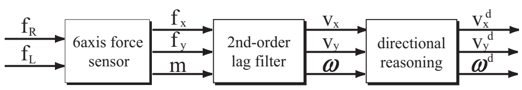


Figure 5: Block diagram of the power assist system.

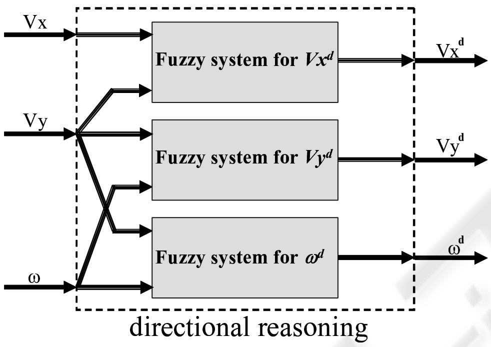


Figure 6: Contents of the block "directional reasoning".

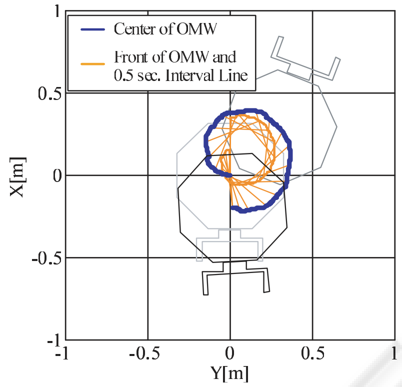


Figure 7: Results when fuzzy reasoning is not applied for improving operability.

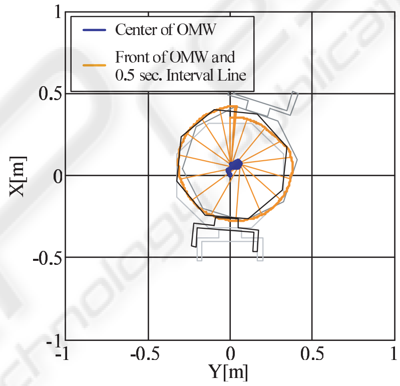


Figure 8: Results when fuzzy reasoning is used by "**Attendant 1**".

sic equation to compensate the difference between the sensor and the actuators allocation (Kitagawa et al., 2004). However, it is difficult to exactly give the force for the sensor to the target direction. Further, how to give the force for the gripper sensor is slightly different depending on persons even for the same target motion of the OMW. The rules of direction inference, in which just lateral motion and rotational motion are considered, are shown in Table 1. In Table 1, Vy represents the lateral velocity of the OMW, and ω represents the angular velocity of the OMW. The forwards and backwards velocity of the OMW is given by Vx.

The system in which fuzzy reasoning was applied just to the lateral and rotational velocity was tested, and it was found that even when the operability in lateral direction was improved, there were still some problems with the rotational movement because of a component Vx that did not allowed to achieved a perfect rotation over the center of gravity of the OMW. A Reduction Multiplicative Factor (RMF) which decreases the value of Vx in the case of rotational motion, and keeps it unchanged in the case of forwards-backwards movement was the solution provided by authors in previous research (Terashima et al., 2006). By using the RMF it was possible to improve the forwards-backwards motion, lateral motion and rotational motion over the gravity center of the OMW.

However, as Vy was subjected to fuzzy reasoning and Vx was not, it was not possible to achieve good operability for slanting motions, like diagonal motion. In the case of diagonal motion, for example, the attendant tries to move the OMW in such a way that the inputs of Vx and Vy are almost the same in the beginnig. Nevertheless, as Vy is subjected to directional reasoning, its value changes. Vx is not subjected to directional reasoning, then its value remains always the same. As a consequence, it is not possible to achieve good operability in diagonal motion.

For solving this problem, Vx was subjected to directional reasoning too using the fuzzy rules shown in Table 2. This rules make it possible to include Vx in the fuzzy reasoning system without disturbing the

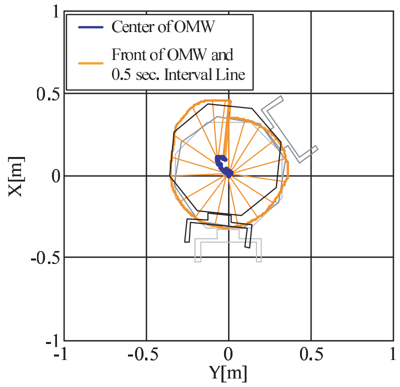


Figure 9: Results when fuzzy reasoning is used by "**Attendant 2**".

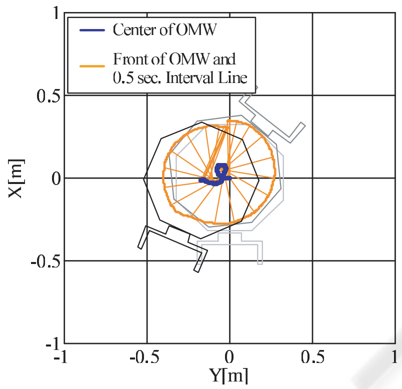


Figure 10: Results when fuzzy reasoning is used by "**Attendant 3**".

values of Vy or ω. The block diagram of the system that considers power assist and fuzzy reasoning is shown in Fig. 5, and the contents of the block labeled as "directional reasoning" are shown in Fig. 6. By including Vx in the ANFIS system it was possible to acomplish a general omni-directional motion.

Fig. 7 shows the results in the case of a counterclockwise rotational over the center of gravity of the OMW when no fuzzy reasoning is used. It is possible to see that there is a deviation in the lateral direction as well as in the forwards-backwards direction. For solving this problem, the fuzzy system was used. It was tuned by trial and error, as explained in (Kitagawa et al., 2004), for an attendant that will be called "Attendant 1", and the results, presented in Fig. 8 shows that the rotational movement was improved considerably. However, when the same system was tested with two more different attendants, called "Attendant 2" and "Attendant 3", the results were not as good as in the case of "Attendant 1", as shown in Fig. 9 and Fig. 10. It means that the system must be tuned in order to respond to the individual characteristics of the different attendants. However, the tuning by trial and error is time consuming and boring for the attendant. For that reason, the automatic tuning of the system by using a neuro-fuzzy system, ANFIS (Adaptive-Neural Fuzzy Inference System) was proposed and developed as described in (Terashima et al., 2006). The ANFIS system of the OMW provided in this paper is shown in Fig. 11.

4 ADAPTIVE CONTROL WITH HUMAN INTERFACE AND RESULTS

In previous research (Terashima et al., 2006), the desired direction of motion of the attendant was input by using the keyboard of the computer of the OMW. However, the attendant could not get a clear idea of the direction in which he wanted to move, neither verify if the real motion of the OMW really corresponded to his desire. In order to provide the attendant with an easy way for inputing the desired direction of motion and for verifying the direction of motion, a human interface consisting of touch panel, as shown in Fig. 2 is used. A GUI (Graphical User Interface) was developed for making easy the interaction with the attendant, as shown in Fig. 3. In this GUI the attendant can draw any kind of motion, like, for example, an slanting motion, or a rotational movement. Moreover, it allows the attendat to follow the motion of the OMW in the screen of the touch panel, and compare the difference between the desired motion and the real motion of the OMW. The complete system, when the touch panel is included, is shown in Fig. 12.

The procedure for applying the touch panel is as follows:

1. First, the attendant draws in the touch panel the kind of movement that he desires to accomplish, as teaching signal for the learning of Neural Networks.
2. Then, the attendant moves the OMW trying to accomplish the desired motion.
3. However, in the general case, there as a difference between the desired motion and the real motion. This difference is used for the training of the ANFIS system of the OMW, as explained in (Terashima et al., 2006).

This system was used for supporting the operation of the attendant in many kinds of movements. Like for example forwards-backwards motion, lateral motion, rotational over the gravity center of the OMW in clockwise and counter-clockwise direction, and many cases of slanting motion. In Fig. 13 it is possible to observe the simulation results of one attendant for the case of diagonal movement to the upper right corner of the XY system shown. Fig. 13 (a) shows the diagonal trajectory obtained before tuning is accomplished. It is possible to see that it is more an arc than an straight diagonal line. By using the same input data used in Fig. 13 (a), the system is tuned by using ANFIS, and the trajectory obtained after the tuning is shown in Fig. 13 (b). It can be observed that the trajectory has been improved, as expected. The number of data used for the training of the ANFIS was in the range of 3500 $\sim$ 4000 data, and the learning time was around 30 [s] $\sim$ 40 [s] in a Pentimum III 1 [GHz] personal computer. The system was tested by experiment, for the same attendant, with the results shown in Fig. 14 (a) for the case before tuning, and Fig. 14 (b) for the case after tuning. As in the case of the simulation, the trajectory obtained in the experiments is not so good before tuning, but it was improved after the tuning of the ANFIS system of the OMW.

5 CONCLUSIONS

An innovative human-interface using a touch panel that provides easy input and feedback information in real time of the operation of a power-assisted wheelchair was developed. Furthermore, adaptive control using a neuro-fuzzy system was proposed in a human friendly fashion by means of a touch panel as a human-interface for improving the operability of the wheelchair. The system was tested by simulation and experiments, and its efectiveness was demonstrated.

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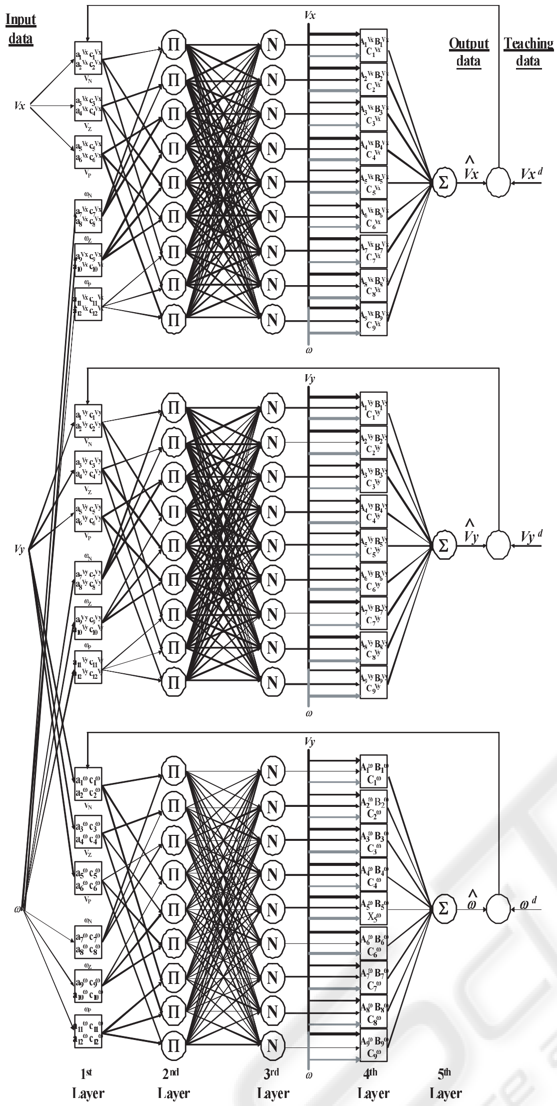

Figure 11: ANFIS systems of the OMW.

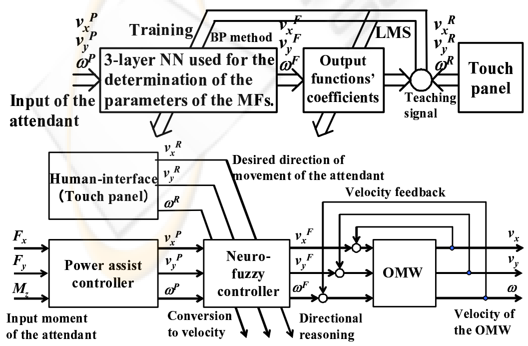

Figure 12: Complete system when the touch panel is included.

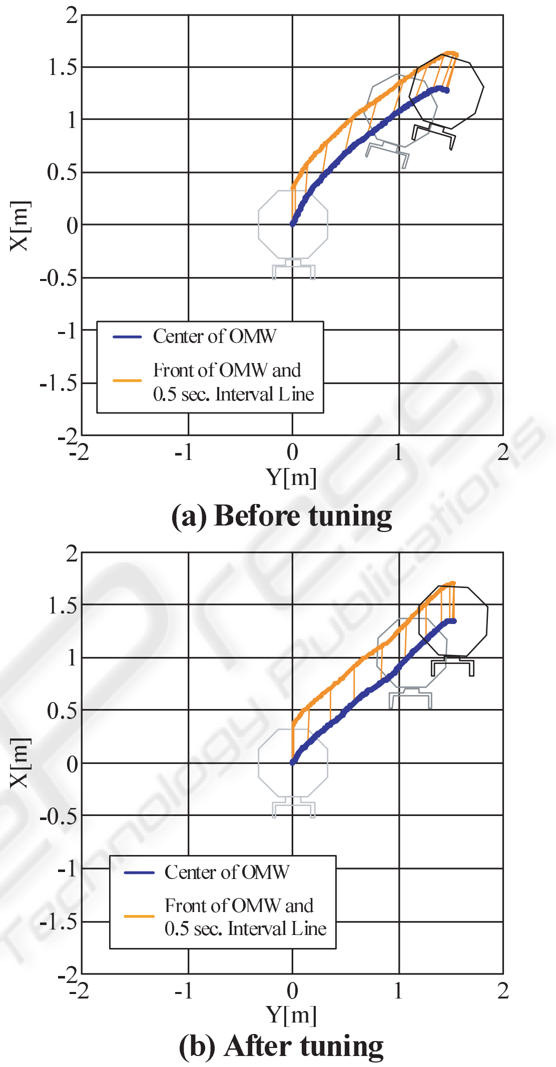

Figure 13: Simulation results for one attendant in the case of diagonal movemement to the right.

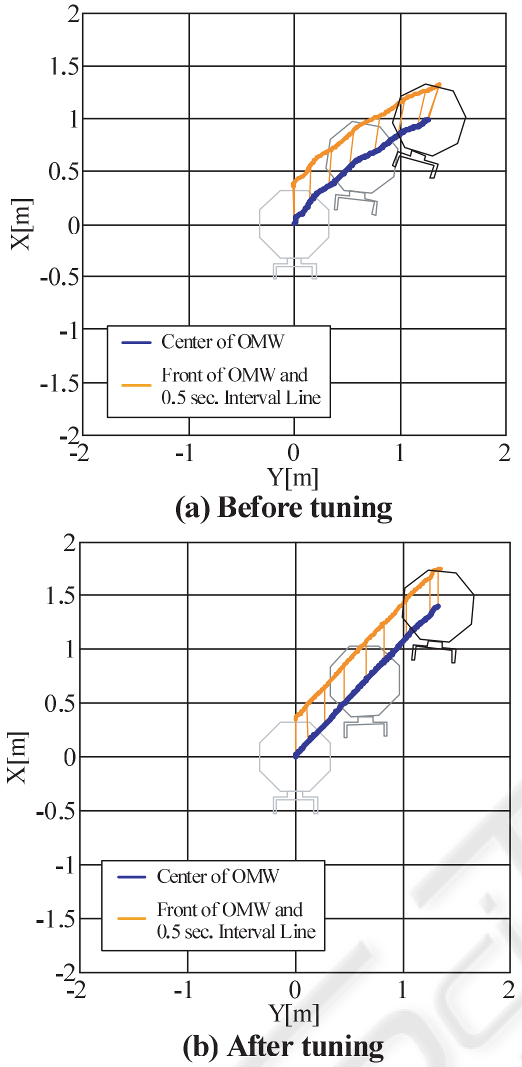

Figure 14: Experimental results for one attendant in the case of diagonal movemement to the right.