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Preamble Review of Autonomous Wheelchair Control Mechanism

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Abstract: *Intelligent Wheelchair (IW) interface is used for providing more convenient and efficient interface to the people with disability. Robotic wheelchairs extend the capabilities of traditional powered devices by introducing control and navigational intelligence. The paper presents an exhaustive literature review in robotic wheelchair control mechanism. The main theme is to control the wheelchair according to signals from the input source. The paper presents different control mechanisms, their advantages, limitations, strengths, weaknesses as a preliminary review.*
Keywords : *Autonomous Wheelchair, Bio-Potential Signal, Motion Signal, Voice Signal, Wheelchair Control.*

I. Introduction

Intelligent Wheelchairs have a big role in the life of people with Disabilities to direct them. One broad area in intelligent wheelchair is interfaces of Autonomous Wheelchair. The purpose is to develop the IW interface for providing more convenient and efficient interface to the people having a disability in their limbs. Traditionally Electrically Powered Wheelchairs (EPWs) cannot satisfy the needs of elderly and disabled users so many alternative control methods have been developed to help improve their quality of life. Intelligent wheelchair control systems are developed using various methods and techniques. It aims to connect user's mind to the wheelchair actuator. The User gives commands to wheelchairs via interface and specifies the designated direction to move. The main issue is centered towards controlling the autonomous wheelchair.

II. Literature Review

In the past decade, a lot of intelligent wheelchair control systems were developed using different methods and techniques. Human-computer interaction plays a big role to provide an interface using methods such as Bio-potential based Methods, voice based method, Motion-based method and Image analysis method.

a) Image Analysis Based Methods

As a hands-free interface, head gestures has been applied in some existing IWs such as WATSON [1].The system was feasible in both indoor and outdoor environments. A real –time stereo face tracking and gaze measurement system was developed to measure the head pose and gaze direction simultaneously. Normalized Correlation was adopted for the template matching of facial features to cope with the changes in lighting conditions. A EWC control with gaze direction and eye blinking [2] is proposed. The gaze direction was expressed by horizontal angle of gaze, and it was derived from the triangle form formed by the center position of eye and nose. The gaze direction and eye blinking were used to provide the direction and timing command. The combination of a vision interpretation system and an electric wheelchair control system was used with differential steering mechanism. A EWC control system with the human eye-only EBEWC [3] is proposed. To estimate the gaze location, pupil knowledge is used. The system detects eye based on a deformable template method which detects the rough position of the eye. In case of failure of this method, Viola-Jones classifier in the OpenCV library detects eye. The adaptive Threshold method was applied for pupil detection. The head gesture based control of an intelligent wheelchair [4] used a combination of Adaboost face detection and camshaft object tracking algorithm to achieve accurate face detection, tracking and gesture recognition in real time. By detecting frontal face and nose position, head gesture is estimated and used to control the wheelchair. The hand gesture recognition system [5] was used to control the wheelchair in which the form and position of a user's hand determine the wheelchair direction. The IW was controlled by the acknowledgement of an object using the technique of geometric recognition with a skin detection algorithm that was based on probability distribution in color spaces. A human-wheelchair interaction [6] is proposed in which lips are detected by adaboost algorithm method training classifier and the head gestures are determined by comparing the lip position with a fixed rectangle. The system was robust enough in noisy environment also. Kalman filter with adaboost algorithm [7] greatly improved the lips detection precision. It improved the lips detection precision. Haar-like features were used to form the weak lips classifiers. Haar-like features and Adaboost learning algorithm was combined for hand gesture detection with the classifier [8]. A popular method to recognize bare hands is the moment of area method. A hand gesture recognition system [9] was proposed that works well with bare hands or gloved hands based on template signature generation. In this, template signatures of gestures were searched first and then the gesture part was separated from the rest of the image. Several methods have been used to recognize hand shapes such as glove-based methods, the method of ngertip markers and the hand with markers. A hand shape recognition method [10] is presented based on curvatures of the nger portion of the hand extracted from image contours. Signatures were generated by combining the contour geometry with the non-dimensional quantities. A HGI [11] is developed using both identity authentication and facial pose estimation. Identity verification was performed by two-factor face authentication, which was implemented by the combination of TICA and MRP. Template matching was performed based on a synergistic neural network (SNN). Use of face-inclination and mouth shape information in the intelligent wheelchair [12] is proposed using statistical analysis and k-means clustering. It achieved accurate recognition of user's intention with minimal user motion, robustness to a cluttered background based on discriminating between intentional and unintentional behavior.

b) Bio-Potential Based Methods

Another possible human-machine interface is the use of nonverbal information such as bio-potential signals, including EMG, EEG and EOG signals. HCI is regarded as one of the key technologies in the human-in-the-loop control system [13] because the human's information system is different from machinery system. MR. HURI used EMG signals, face directional gestures and voice for the HCI. A wearable EMG-based human-computer interface [14] is proposed in which user expresses his intention as shoulder elevation gestures. A double threshold method was used to recognize the wheelchair control command using the time difference of muscle activation. A hands-free control system RoboChair for EPW was proposed based on EMG signals recorded from eyebrow muscle activity by using a simple CyberLink device. EOG signals detected from eye movements are used to adjust wheelchair speed. These interfaces make available to the person some experiments, but can't be used as commercial available wheelchair. An HMI interface was built using finite state machines for controlling the intelligent wheelchair via forehead EMG and EOG signals [15]. A method using hands-free manipulation interface [16] was used that applies the EOG and EMG bi-potential signals obtained from a simple BCI to recognize the gestures, such as closing the jaw, wrinkling the forehead, and looking towards left and right. PointBug algorithm [17] and TangentBug algorithm [18] were used to navigate the wheelchair in auto controlling method. The TangentBug algorithm used two basic behaviors: motion toward the target and obstacle boundary following. The performance of PointBug varied in different environment and obstacle location.

c) Motion Based Methods

For human-machine interaction, human motion recognition is also used. Many different motion recognition approaches are based on hidden Markov models and artificial intelligence (Fuzzy logic and neural network). A Head motion recognition technique [19] is used as an algorithm of microcontroller system. Head motion recognition was based on the force measurements yielded by an accelerometer attached to the head. A robotic wheelchair with three motion control modes [20] is proposed. Autonomous control mode, manual control mode and remote control mode are used. To facilitate the wheelchair in remote control mode, face recognition and hand gesture recognition were combined. The system extracted skin color regions by color segmentation and identified the user's face by computing DIFS and DFFS. Dynamic finger movement tracking and voice command based smart wheelchair [21] was developed in which word detection algorithm and normalization algorithm were used with MATLAB and flex sensors. To track the movement of fingers, flex sensors were used.

d) Voice Based Methods

Voice control is utilized in combination with the navigation assistance within the NavChair assistive wheelchair navigation system [22]. Voice control can also be implemented in a wheelchair without navigation assistance. It was based on the verbex speech commander that identifies the sound signal and transmits computer code to steer the chair.

III. Issue-wise Discussion

Various methods and algorithms are used to control the intelligent wheelchair. An Adaboost algorithm with face-inclination and mouth-shape information produced the best performance with an average accuracy of 96.5%, while the face based method had an accuracy of 87.5% and the headband based method had an accuracy of 88%. TICA and MRP algorithm has a high success rate in authentication. Modified SC-MELT showed overall performance 96.00% in 2 degree learning interval scenario. The point Bug algorithm requires minimum no. of information as compared to the other bug algorithm such as DistBug while Tangent Bug algorithm is most appropriate due to based on range sensors. Kalman filter with adaboost algorithm improves the lips detection precision and reduces the detection time.

Many access methods have been developed for IWs and classified as intrusive and non-intrusive. Intrusive methods use glasses, a headband with infrared / ultrasound emitters to measure the user's intention. Non-intrusive methods don't require any additional devices attached to the user's head or face. According to Table I, nonintrusive methods consist of voice-based and vision-based methods. Head, face, eye gaze and voice data are used as a primary source for information to control the wheelchair. Each and every control method is implemented using different hardware devices and software interface. Different control methods are implemented in intelligent wheelchairs with minimum supporting commands to provide more convenient and effective access of wheelchair.

Table I: IW Controls in Literature

		Intelligent Wheelchair	Feature	Device	Supporting Commands
Intrusive Interface		Y.L. Chen et-al	Head Orientation	Tilt sensors, microprocessor	Go, back, left, right
		SIAMO Project	Eye Gaze	Electrode	Go, back, left, right
		Wheelesley	Eye Gaze	Infrared sensors, ultrasonic range sensors, electrodes EOG	Go, stop, back, left, right
Non-intrusive interface	Voice	Siamo Project	Voice	Ultrasonic Sensors, infrared sensors, camera and laser diode	Go, back, left, right
		ROB Chair	Voice	Infrared sensors, ultrasonic sensors, head microphone	Go, stop, speed up, speed down, rotate
		NAV-Chair	Voice	DOS-based computer, ultrasonic transducer, laptray, sonar sensors	Go, stop, back, left, right
		TAO project	Voice	Sensors, 2 processor boxes	Go, stop, back, left, right
	Vision	HGI	Head and Nose	Webcam, ultrasonic sensors, DAQ	Go, Left, Right, Speed Up, Speed Down
		SIAMO	Head	CCD color-micro camera	Go, Left, Right, Speed up, Speed Down

*source: Vision based interface system for hands free control of an intelligent wheelchair [13]

IV. Common Findings

Bio-potential based methods are relatively costly. On the other hand, Image analysis method doesn't insist any load to users and is realized with comparatively cheap. VC 6.0 and OpenCv were mostly used as software interface. Intelligent interface b/w users and IWs can be categorized as such

- Hand-based control (Joystick, keyboard, mouse, touch screen)
- Voice based control (audio)
- Vision-based control (Camera)
- Sensor based control(Infrared, sonar, pressure sensors)

Electronic systems in common are sensors, actuators, cameras, encoders, accelerometers and gyroscopes, signal processing units, software that translates user's commands into actions. Autonomous navigation capability is provided for safety, flexibility, mobility, and obstacle avoidance. MATLAB is used for simulation purpose in various methods. Different Software program environments such as VC6.0 and OpenCV are used in most of the control interfaces. Digital signal processor with microcontroller is used as a main functional unit. MS windows XP as an operating system and MS visual C++, MS visual basic 6.0 languages are used mostly in interface.

4.1 Advantages

- Joystick based wheelchairs had detailed movement direction and speech control properties.
- Voice based control reduced the physical requirement of operating a wheelchair.
- The assistive control provides enhanced mobility for the elderly and disabled people having restricted limb movements.
- Due to the low cost of the sonar sensors, the combination of sonar sensor and the VFH system in commercial wheelchair is beneficial.
- The movement tracking method has superiority over gesture recognition method because in movement tracking, the application is to be trained instead of user.
- Deformable template method takes less time than classifier methods to detect eye.
- Kinect is advantageous to use as an input device to assist the elderly with greater confidence because it provides a more natural way of interaction when giving directions using the wheelchair.

- HGI system has been improved by including identity authentication. The direction of the face can be controlled intentionally when needed.
- Kalman filter with adaboost algorithm improves the lips detection precision and reduces the detection time.
- A hand gesture system with bare hands and gloved hands eliminates interference by the wrist and the rest of the hand very successfully.
- Haar-like feature-based systems can operate much faster because of focus more on the information within a certain area of the image rather than each single pixel. It is used to formulate weak lips classifier.
- Joystick based control has the advantage of detailed movement direction and speed control.
- The gesture based system requires minimal user motion, making the system more comfortable and more adaptable for the severely disabled than conventional methods.
- Double threshold method was used to discriminate a time difference of muscle activation due to the difference of muscle properties.
- Wheelchair system integrated with customized user interfaces, various sensors and different types of controllers made the function and controlling of a wheelchair much simpler and safer and made it more stable and handy for disabled persons.
- Appropriate algorithms for controlling the wheelchair aids the user in avoiding obstacles such as walls, moving obstacles like people and other wheelchairs, planning collision-free paths and moving safely in a jumbled environment without taking much of the user input.

4.2 Limitations

- Joystick based wheelchair requires complex wrist movement.
- The laser range sensors are costlier as compared to the other sensors. Sonar sensors are unable to detect obstacles which are either too high or too low from its position.
- Mostly vision based interface systems were unable to discriminate between intentional and unintentional behavior.
- Voice based interface system was vulnerable against noise.
- Detecting the iris position needs the user sees only in the direction of displacement so it can’t be used by people with problem at neck level. In face based interface, face recognition was necessary for everyone before the operation.
- Gaze direction can’t be fully controlled intentionally when needed. Intentionally and unintentionally information must be separate out. Many wheelchair systems required the help of a person to configure at initial stage.
- In the face based interface, sometime face registration was necessary before the operation.

V. Scope of Work

- A normal head movements that don’t aim to control the wheelchair need to distinguish and omit from the other signals.
- A major challenge faced by the hand gesture recognition system is to isolate the gesture section from the entire image of the person’s hand.
- EMG classification methods such as support vector machine (SVM) and other neural network based algorithm can also be applied to improve the classification speed and accuracy.
- The EMG signal based method was less efficient to use in an environment with concave obstacles rather than the manual method.
- More work can be undertaken to develop intelligent functions to help the people with severe Cognitive impairment along with the physical impairment. User friendly interfaces adapted to the specific need of cognitively impaired person, has to be developed.
- The efficiency of the voice command control system can be improved by implementing a neural network based algorithm.
- The gesture based interface system needs to be evaluated in both indoor and outdoor environments where cluttered background, changing lighting conditions, sunshine and shadows may bring complications.
- Shared control strategy can be used to improve the usability of wheelchair while Multimodal interface can be used for better control of the wheelchair.
- Laser sensor can be used instead of IR sensor to increase the sensitivity of the system.
- There is need to remove ambiguity in possible desired goals that fails system to decide accurately the intended goal.
- The system should be functioned in crowded and complex environment in indoor and outdoor that needs extra sensors to detect and avoid obstacles.

VI. Conclusion

Smart wheelchairs are needed to enhance autonomous or semi-autonomous wheelchair working, which could enable the elderly person as well as people who are either suffering from motor impairment or cognitive impairment or both, to remain mobile and lead their life safely and with ease. Although many works have been previously undertaken in the field of controlling the autonomous wheelchair, still there is a lot of work desired. New algorithms in neural network could help in controlling the devices more efficiently. Shared control can be used in situations where the assisting device combines the control input coming from the robot and the user in order to cooperate in the task.

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