A Survey of Human-centered Intelligent Robots: Issues and Challenges

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***Abstract*—Intelligent techniques foster the dissemination of new discoveries and novel technologies that advance the ability of robots to assist and support humans. The human-centered intelligent robot has become an important research field that spans all of the robot capabilities including navigation, intelligent control, pattern recognition and human-robot interaction. This paper focuses on the recent achievements and presents a survey of existing works on human-centered robots. Furthermore, we provide a comprehensive survey of the recent development of the human-centered intelligent robot and discuss the issues and challenges in the field.**

***Index Terms*—Human-centered robots, human-robot interaction, intelligent control, navigation, path planning, pattern recognition.**

I. Introduction

IN recent years, robots called "anthropocentrism" or "human-friendly" system have been more and more frequently appeared in restaurants, hospitals and service areas, for example, homework robots, entertainment robots, assistive robots, residential surveillance robots and robots for children's education [1]−[3]. Human-centered robots are not only seen in science fiction movies, but they are also coming into our lives. Intelligent robots aim to understand the increasingly coupled relationships between human and machine. With the increasing trend towards home service and health care, we are facing the need for improved navigation systems, intelligent control methods and pattern recognition techniques for human-centered robots capable of performing in these unstructured environments.

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Compared with the traditional robots such as industrial robots, the human-centered robots require completely different performance measurement requirements [4]. Several groups claimed that human-centered robots must be autonomous and capable of providing a high level of safety, compliance, comfort, adaptability, functionality and flexibility [5]. The authors believed that human-centered robots should have natural communication channels [1], including not only language but also facial gestures and expressions [6].

With the development of communication technology and computer technology, more and more methods have been applied to the navigation and planning of mobile robots. The navigation of mobile robots mainly includes: environmental map model matching navigation based on environmental information, landmark navigation based on various navigation signals, visual navigation, odor navigation [7] and sound navigation [8]. In 2000, AREN robot achieved absolute robot localization by doing matching between recently collected landmarks and the reference map [9]. Natural landmark navigation is accomplished by the identification of the natural environment. The stability and robustness of landmark detection can be the main problems [10]. Visual navigation is mainly used for the detection and identification of obstacles and road signs. The most widely used navigation methods in indoor and outdoor are based on local vision [11], [12].

Currently, intelligent controls have been widely applied to human-centered robots. In [13], the authors presented an adaptive impedance controller of an upper limb robotic exoskeleton using biological signals. In [14], the authors also proposed a model predictive control (MPC) scheme for the nonholonomic chained systems. The proposed MPC scheme employs a general projection neural network (GPN) to iteratively solve a quadratic programming (QP) problem over a finite receding horizon. In [15], the authors studied the optimal distribution of feet forces and control of multilegged robots with uncertainties in both kinematics and dynamics and proposed a hybrid task-space trajectory and force tracking control based on fuzzy system and adaptive mechanism that are used to compensate for the external perturbation, kinematics, and dynamics uncertainties.

In many applications, it is essential to study detection and realization of the user's movement intention instead of a predefined motion. In [16], impedance control was proposed to achieve the offset of a predefined reference trajectory. In [17], adaptive control was employed to adjust the robot behavior and make the robot more flexible. In [18], the authors proposed a target grabbing strategy for a telerobot based on developed stiffness display device in which robots can mimic the characteristics of humans to carry items. In [19], the authors proposed a robotic system to help a stroke patient recover.

With the development of wearable devices, smart home and Internet of things in the circle of science and technology, human-robot interaction would gradually become the key issue to develop a comprehensive intelligent life. For example, intelligent mobile phone equipped with geographic space tracking technology [20], motion recognition technology used in a wearable computer, stealth technology and immersion game [21], haptic interaction technology used in virtual reality, remote control and telemedicine [22], speech recognition technology applied to call routing, home automation and voice dialing [23], silent speech recognition for people with speech disorders, human computer interface technology based on electroencephalogram(EEG) applied to "mind wheel chair" for people with language and action disorders [24].

The rest of the paper is organized as follows. Navigation and local planning for human-centered robots are introduced in Section II. The development status and challenges of intelligent control are described in Section III. Pattern recognition for human-centered robots is carried out in Section IV. The application of Human-robot interaction for human-centered robots is proposed in Section V. Finally, conclusion of this paper is given in Section VI.

II. Navigation and Path Planning

The mobile robot is a set of functions and capabilities, i.e., context-aware, dynamic decision-making and planning, behavior control and enforcement and other functions into one integrated system. At present, most of the flexibility of robots is repeated programming, and working environment is relatively fixed. As the scope of human activities and the exploration of space is the symbol of human progress, the robotic mobility is also reflected in the movement space. In order to gain greater independence, the higher flexibility and intelligence are required for robots to complete the task and enhance the ability to adapt to the environment.

Path planning is the key issue for autonomous mobile robots. Path planning and motion control problems are not only very important to accomplish autonomous navigation and other complex intelligent tasks, but also embody perception ability and intelligence of robots. The path planning includes model-based planning and case-based planning. The former planning is according to the known environmental model or perception map knowledge to plan; the latter is according to the planning of existing knowledge by using the matching method to solve the planning problem. Case-based planning applies to more complex but relatively fixed environments, because of the increasing uncertainties and a large amount of computation, we need to constantly update the case library [25].

Taking the assistive mobile robots for instance, in [26], a collaborative human-robot decision making navigation method was applied in a simulated task of going through the maze. In [27], a new potential function for path planning was proposed considering the distance between the mobile robot and the target. In [28], navigating a mobile robot through the crowd with human collaboration was investigated, where crowd density prediction and multiple goal extension were involved in the analysis. In [29], a novel method was proposed for a mobile robot to plan its path towards a target through an unknown environment. This method ensures the creation of navigational potential field with no danger of being trapped in local minima. In [30], several convergence path planning methods for robots were introduced, such as Morse decomposition and convergence methods based on sensor, graph, grid, 3D, landmark, neural networks and optimal control theory.

Human has higher requirements on the autonomous navigation ability of mobile service robots. It is required that the mobile service robot can also take the corresponding measures to improve the ability of the mobile robot according to the change of the surrounding environment. Therefore, path planning is an important factor of the intelligent navigation for autonomous mobile robots. In [31], some navigation methods considering the human comfort constraints and social rules were introduced in human-aware robot navigation. In [32], a fully autonomous navigation solution is presented for urban and pedestrian environments. The results showed a success rate of nearly 99 percent over 6 km of autonomous navigation. In [33], an indoor safe navigation method was proposed subject to the limitation of the vision, and this method was able to reduce the collision risk considering the occluded dynamic obstacles out of the robot vision. In [34], a human behavior modelling approach based on reinforcement learning was proposed when the mobile robots interact with human in social environment, where the discrete navigation decision and human trajectory variation were involved in the modelling process. In [35], with a proposed navigation algorithm, the mobile robot could successfully pass through the moving obstacles without the obstacle velocity information. In [36], the incremental algorithms about the grid-based navigation were proposed to efficiently update configuration space collision maps.

In addition, people's demands for vehicles are increasing. Intelligent autonomous vehicles emerge as the time's require. The autonomous ground vehicle (AGV) or outdoor intelligent mobile robot detects the surrounding environment and obtains the information of the roads and obstacles by using on-board sensors. Then, the AGV can make decisions autonomously, plan the path, and automatically control the speed and direction of the vehicle so that it can travel safely and reliably on the road. Compared with the manned vehicle, the AGV regulates the behavior of vehicles, reduces traffic accidents caused by drivers mental and physical strength, improves the perception of the environment and reduces reaction time. The AGV embodies the intersection and synthesis of vehicle engineering, artificial intelligence, automatic control and computer science. This is the future development trend of vehicles. The key technologies of autonomous vehicles include digital map technology, visual technology [37], [38], sensor information fusion technology and path planning technology [39], [40].

However, in the vision navigation technology, the image processing speed problem has not been solved. The real-time performance of the system is also a problem that cannot be ignored. The detection range and accuracy of the non vision sensor is not ideal compared with the visual navigation system, and it is not suitable for some high precision navigation tasks. It is an important task to study the general interface module of robot navigation. In addition, multi-robots system is also a development direction of the robot technology [41]. Navigation and local planning of multi-robots system play a key role in the robotic systems [42]−[45].

The application scope of intelligent algorithm in robot local planning has great limitations, such as neural network modeling. And application is often limited in the cognitive environment, such as robot map building [46], [47]. At the same time, because the current process is mainly used in local planning feed forward network and signals are required to train, it is difficult to achieve online application; in complex unknown dynamic environment, it is difficult for fuzzy logic to extract fuzzy rules, and navigation performance is not ideal [48], [49]. Therefore, in the local planning of mobile robots, intelligent methods have great development space. The application of neural networks in local path planning is a process to avoid the unknown obstacles by using the local information obtained online in the shortest possible time [50]. At the same time, fuzzy inference and genetic algorithm can be introduced into the neural network to achieve path planning [51]. In [52], the authors presented a modified pulse-coupled NN model for the real time path planning considering the obstacle avoidance in a time-varying environment. In [53], the authors presented neural dynamics for landmark orientation and angular path integration.

III. Intelligent Control

For the human-centered intelligent robot, intelligent control is an important development direction. At present, intelligent control has been widely applied to human-centered robots [54]−[56]. The development of the artificial neural network has greatly promoted the development of intelligent control theory, and it makes the robot more humane which can think from the perspective of people.

Furthermore, intelligent controls are applied to all aspects of the human-centered robots [57]. The robot is a complex nonlinear, strongly coupled, multivariable uncertain dynamic system. Moreover, it is difficult to establish an accurate mathematical model with the prior knowledge of the existing robot dynamics model. Even if a model is established, it is very complex, and it cannot meet the requirements of real-time control. The emergence of intelligent control provides a new way to solve some problems in robot control. In [58], the authors studied the tracking control problem for an uncertain n-link robot with full-state constraints and designed an adaptive neural network (NN) control for the robotic system with full-state constraints. In [59], neural network control was presented for a rehabilitation robot with unknown system dynamics. In [60], adaptive robust force/motion control strategies were presented for mobile manipulators under both holonomic and nonholonomic constraints in the presence of uncertainties and disturbances. In [61], the authors investigated optimized adaptive control and trajectory generation for a class of wheeled inverted pendulum (WIP) models of vehicle systems.

In the literature, fuzzy approximation and designed disturbance observers were utilized to compensate for the disturbance torques caused by unknown input saturation, fuzzy approximation errors, viscous friction, gravity, and payloads in [62]. In [63], force/motion tracking control was introduced for nonholonomic mobile manipulators with unknown parameters and disturbances under uncertain holonomic constraints. In [64] optimal feet forces' distribution and control were proposed for quadruped robots under external disturbance forces. In [65] automatic motion control is introduced for wheeled inverted pendulum (WIP) models, which were widely applied for modeling of a large range of two wheeled modern vehicles. In [66], neural control was proposed for bimanual robots with guaranteed global stability and motion precision. In [67], neural network control problem was studied for an uncertain n-link robot with full-state constraints and a robotic manipulator in the presence of input deadzone and output constraint. In [68], an adaptive fuzzy neural network controller was proposed for a constrained robot using impedance learning.

Learning control techniques including neural networks, fuzzy logic control and adaptive control have been widely applied in human-centered robots [69]−[71]. In the future, works of human-centered robots, the artificial intelligence technology will give full play to their advantages and play a leading role. However, intelligent control needs to be improved for the complex system. If the system is complicated, the failure rate and the cost of the intelligent control system is higher than that of the traditional control system, and the superiority of intelligent control will be in doubt. In addition, most control designs based on neural networks still stay at the stage of simulations, and the reports on practical systems are seldom.

IV. Pattern Recognition

It is particularly important for humans to recognize the optical information (obtained through the visual organs) and the acoustic information (obtained through the auditory organs). These are the two important aspects of pattern recognition. An important form of information processing for robots is the identification of the object and the environment. Pattern recognition technology, as a basic subject of artificial intelligence technology, will have a large space for development. The major authoritative research institutions around world have begun to focus on the pattern recognition technology as research emphasis. The representative products on the market are optical character recognition and speech recognition system. As the most basic problem in pattern recognition, image analysis and video analysis have made some outstanding achievements in the field of human-centered intelligent robots.

Among literatures, in [72], a robust multiple instance online learning algorithm was proposed to solve the problem of tracking the object when the video is without any information except the first frame. In [73], a novel online object tracking algorithm with sparse prototypes was introduced, the partial occlusion and motion blur are taken into account, and the tracking drift is reduced by the algorithm. In [74], a hybrid algorithm for image segmentation was presented by using the notion of particle swarm optimization (PSO) and clustering techniques. All moving and still objects in video images can be detected accurately with the help of efficient image segmentation techniques. In [75], a semantics-sensitive integrated matching for picture libraries was proposed for reducing the inaccurate segmentation and clarifying the special region semantics. In [76], a new variable block-size image compression scheme was presented. The use of pattern parameters at the receiver together with the quadtree code reduces the cost of reconstruction significantly and exploits the efficiency of the proposed technique.

The exploration of unknown environment is one of the most advanced topics in the research field of humanoid robot, and the precise pattern recognition is the key technology of the unknown environment. In [77], [78], the authors proposed a novel feature extraction for robust electromyogram(EMG) pattern recognition. In [79], the authors studied an EMG-based pattern recognition approach in the multi-DOF (degree of freedom) advanced upper limb prostheses. In [80], an EMG-based pattern recognition method was proposed for a multifunction myoelectric hand, and type separability and recognition accuracy are improved by the proposed linear to nonlinear feature projection. In [81], the linear discriminant analysis and wavelet packet transform were developed in the real-time EMG pattern recognition. EMG pattern recognition has been developed to interpret the performance of different functional movements. It can be used to develop the movement control techniques of assistive devices for people who are physically disabled. In [82], a heuristic fuzzy logic approach EMG pattern recognition was proposed for the myoelectric prostheses control.

The future research areas of the pattern recognition include the recognition of the content, as well as adaptive learning, small sample learning, multi-modal learning, multi task coordination and so on. Autonomous learning will be the trend of future research. In addition, speech recognition technology is gradually becoming the key technology of human robot interface in information technology. Biometrics is the most concerned security authentication technology. Human is willing to forget all the passwords, throw away all the cards and use their uniqueness to identify identity and confidentiality. Those technologies also will benefit the development of human-centered intelligent robots.

V. Human-Robot Interaction

As a branch of the development of human-centered robots, mobile robots with human-robot interaction [83] can accomplish the service work which is beneficial to human beings [84]. In some specific applications, it has an irreplaceable position in general mobile robots. At present, due to the limitations of the level of artificial intelligence development, autonomous intelligent mobile service robot is still difficult to design [85]. Mobile service robot is generally a human-machine-environment system. In the system, human's participation and coordination are also very important to improve the performance of the system [86]. Reference [87] focused on the elderly and the disabled service robot and proposed man-machine intelligent fusion method based on human-computer interaction. In the system of human-robot environment, the mobile robot has the ability of pose prediction, pose correction and anti-collision. On the other hand, the operator can get a variety of information from the robot through the friendly man-machine interface according to the information command and coordinate the movement of the robot. However, ubiquitous computing characterized by invisible and mobile, and a virtual reality environment characterized by three dimensions, will be a major challenge and research goal.

Human robot interaction is the focus of the current information industry competition, and human-computer interaction is regarded as the key technology in the world. The intelligent technology has two important application trends. One is the personification trend represented by virtual reality, and the second one is miniaturization trend represented by smart watches. Human robot interaction is a bottleneck technology of facing these two trends. Human centered, natural, high efficiency will be the main targets of the new generation of human-computer interaction technology. In [88], the authors reported the fabrication of a transparent and stretchable iHMI (integrated human machine interface) system composed of wearable mechanical sensors and stimulators, and the control of a robot arm for various motions and the feedback stimulation upon successful executions of commands are demonstrated using the wearable iHMI system. Since service robots directly interact with people, finding "natural" and easy-to-use user interfaces is of fundamental importance. Reference [89] described a gesture interface for the control of a mobile robot equipped with a manipulator. In [90], the authors presented the notion of neglect tolerance as a means for determining how robot autonomy and interface design determine how free time can be used to support multitasking, in general, and multirobot teams, in particular. In [91], the authors showed a fully integrated system that instantiates our theoretical framework within a working robot system. The system successfully solved a series of perspective-taking problems and used the same frames of references that astronauts do to facilitate collaborative problem solving with a person.

Multi-modal interaction is a rapid development of human-robot interaction technology in recent years. It not only adapts to the "human centered" natural interaction rules, but also promotes the rapid development of the information industry in the Internet era. Microsoft Asia Research Institute of multimodal user interface invented digital ink to operate pen interactive equipment, high quality ink rendering technology and intelligent ink analysis technology. It can not only be used as character recognition and graphics rendering, but also can be used for a new "ink" data model, making handwritten notes easier to read, acquire, organize and use.

However, there are still many deficiencies in the way of human-robot interaction. In the field of human-robot interaction technology, although the researchers have tried many new types of interaction, such as somatosensory interaction, eye tracking, voice interaction and biological recognition, but most of the interactions are not widely used. Somatosensory interaction is only limited in the field of games since it is unstable. The most closely related with somatosensory interaction is virtual reality device. Voice interaction is generally monotonous and cannot give the users constructive suggestions.

So far, researchers are still trying to explore biometric technology and gesture control technology. Biometric identification is based on the vital signs of human beings, including fingerprints, iris, face and even the blood vessels in the eyes, which may help the intelligent terminal device to verify the identity of the user. When cloud services are more widely used, biometric technology will help us to more easily and securely login in the cloud account. In the near future, the biometric technology will enable us to throw away a credit card, wallet or cash, and all the information will be bounded to our own vital signs. In addition, combined with high fidelity image technology, gesture control technology also has a very good application prospect.

VI. Conclusions

In this paper, we have presented a survey of existing works on human-centered robots from navigation, intelligent control, pattern recognition and human-robot interaction perspectives. Modeling, navigation, path planing, cognitive computing, pattern recognition, EEG and EMG signal processing, intelligent control in an unstructured environment, and cognitive modeling for human-centered robots have been studied. A comprehensive review of the recent progress in the field has been provided. Furthermore, the potential research direction of human-centered robots has been discussed.

Human-centered robots are significantly increased in our ordinary life as a servant, secretary, or companion to perform intelligent robotic functions such as intelligent humanoid robots, quadruped robots, wheeled robots, biomorphic robots, exoskeleton, wearable robots, wheeled balance transporter, variable stiffness actuators, etc. Human-centered intelligent robots aim to understand the increasing couplings among humans and robots. Although much progress has already been made to solve these challenges and issues for human-centered robots, much work remains.

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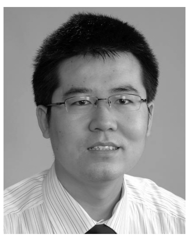

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