Towards an Autonomous, Unmanned Aerial Vehicle for Indoor Flight in Healthcare; a Review of Research Challenges and Approaches

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Abstract—The development of advanced indoor navigation systems for Unmanned Aerial Vehicles (UAVs) has aroused extensive interest recently because of its great potential. In comparison to outdoor flight, indoor navigation poses several unique challenges in stability and control for quadcopter operability. This review paper investigates these research challenges and explores solutions that exist to address them. Embedded issues concerning real-time object detection and recognition, client-server communications and decision support for the purposes of healthcare administration by a prototype drone intended for indoor flight are examined within the restricted, GPS-denied environment. Approaches and supporting technologies are examined toward a solution that enables autonomous UAV indoor flight for patient care, to facilitate independent living through personalized robotics.

Keywords—Assistive technology, autonomous agents, collision avoidance, healthcare, medical decision support systems, navigation, position control, unmanned aerial vehicles.

I. INTRODUCTION

Indoor inactivity, such as due to depression, is a serious global community concern, and in severe cases can lead to suicide or death that may have been prevented with more dedicated, personalized healthcare treatment. Caregiver support for a variety of mental and physical disorders, including counsellors and triage care providers, may not be extensively available or administered in a timely manner. Further, inhibitive costs and remote location may restrict access to regular consultations or treatment.

The proposed work focuses on the development of a modern Unmanned Aerial Vehicle (UAV) which operates autonomously, for mental and physical health assessment, by addressing key research challenges in this field. Challenges associated with such development have been broadly identified in the literature, and correspond to the focus of each Section detailed within this concept paper.

These relate to: autonomous flight, navigation and obstacle avoidance (Section II); flight control and stability (Section III); voice recognition in noisy environments (Section IV) and real-time decision support for health status classification (Section V).

Autonomous navigation for indoor flight remains a research challenge, with most of the proposed approaches for autonomous flight focused on systems that are for outdoor operation, with GPS-enabled flight control. Various methods have been applied to achieve autonomous navigation [1] to [6]. Sensing technologies utilized for this purpose have included: integration of monocular cameras [2], and motion sensor devices [3], on-board processing smartphones [1], infrared sensors [4], and dedicated algorithms for optimal path finding [5], [6].

Research methods are introduced to aid in dexterity in UAV control for flight stability [5], [7] to [9]. Such methods utilize reflective markers for indoor quadrotor flight [10], and dedicated algorithms for tuning the UAV PID controller [11], [12]. Maintenance of stability during cases of emergency, such as propeller loss, is addressed [13]. Flight path planning and trajectory analysis are considered towards maintaining in-flight stability, for fully automatic quadrotors [5], [7]. To facilitate autonomous quadrotor operability, strategies for obstacle avoidance are examined [8], [9]. The relationship of stability with autonomous navigation is evaluated [14], [15].

Voice and Speech Recognition (VR and SR) strategies have been applied for robotic control [16] yet are lacking in UAV applications. Data transmission between user and Automatic Speech Recognition (ASR) equipment are investigated [17]. Researchers examine and apply SR in Air Traffic Control (ATC) systems [18], [19] and ground-restricted robotics [16]. While computerized DSS’s have been developed [20] to [23], such as for cancer care [21], blood infections [22] and differential diagnosis [23], a drone-based client-server decision support using querying for mental and/or physical health has not been achieved.
This concept paper evaluates current methods and technologies adapted within the literature toward autonomous flight, towards a new system, Healthbuddy, for indoor healthcare administration with a UAV. The proposed system will use a quadcopter to provide assistive healthcare in the home. The drone will operate indoors to locate a person and, through intelligent, interactive querying, determine the mental and physical state toward effective action. At regular intervals, the drone will autonomously navigate inside the home with aid of camera- and ultrasonic- guidance, to detect and identify the patient through VR and image recognition, avoiding collisions with objects and walls. Once recognized, the patient is questioned by the UAV that wirelessly communicates responses back to a central server and retrieves further queries. Health-based queries are those that require yes/no responses and VR strategies identify and classify the speech response. The DSS operating on the server provides patient analysis through dynamic classification to determine the best course of action for appropriate response, such as alerting a primary caregiver in the event of an emergency.

II. AUTONOMOUS FLIGHT; PATH PLANNING, NAVIGATION AND OBSTACLE AVOIDANCE

A variety of techniques are introduced within the research literature for autonomous quadcopter navigation, flight control and path planning [2], [3], [5], [6], [25] to [28]. Research in autonomous navigation reveals promise in laser [24], camera [2], [3], [25], [26] and infrared sensor [4] technologies. Researchers combine camera technology with SLAM algorithms and off-board processing for path planning in navigation and obstacle avoidance [2], [3], [6], [24], [26] to [32].

A. Navigation, Localization and Mapping

Camera-vision systems have been integrated with UAV technology to enable autonomous flight [1] to [3], [6], [25] to [27]. For path detection and localization, Frew et al. [25] developed a system for autonomous aircraft to follow a road (pre-defined path) using camera vision, where a Bayesian Pixel Classifier is applied to extract the probability of a pixel in an image belonging to a road. For the aircraft to follow the detected road, the height (via sonar) and the lateral angle (using the Bayesian Classifier) of the aircraft from the road are obtained and fed into an outer PID control loop [25]. Various algorithms have been introduced for path planning and flight control; of particular promise, the SLAM algorithm [2], [3], [26], [28] and the ACO algorithm [5].

B. Obstacle Detection and Avoidance

Algorithms for simultaneous estimation of vehicle altitude and elevation of underlying surfaces, in addition to path planning and obstacle avoidance, are examined [6], [24], [25], [27]. Customized hardware solutions addressing these design considerations are explored in [1] and [4], while most commercial drones used for research purposes, as in [6] are not easily modifiable for customized control. Algorithms for obstacle detection and avoidance include camera- and laser-based SLAM [24] and CEO for fuzzy logic control [6]. Grzonka [24] implements a SLAM algorithm in 2-D wherein a quadropter platform, a derivative of the Mikrokopter for flight navigation, is operating in a large class of indoor environments by using efficient variants of 2-D that work on dense grid maps. The navigation system is based on a modular architecture in which different modules communicate via the network by using a publish-subscribe mechanism [24]. In a separate study, a novel CEO-based Fuzzy Logic Controller (FLC) for Fail-Safe UAV has been presented by the authors [6] to expand its collision avoidance capabilities in the GPS-denied environments using Monocular Visual-Inertial SLAM-based strategy. Obstacle avoidance has been implemented [8], [9], [36]; the former utilizing ultrasonic sensor technology, with a state machine and PID controller [8]. Vision-based sensors are applied [36], combining camera tracking with blob detection methods [36].

C. Discussion and Analysis of Applied Methodologies

SLAM methods show utility for the proposed system for path planning [2], [3], [24], [26], [28]. For path planning, improvements in design requirements are identified as: greater processing capabilities [2], [27], [28], [29], [30], such as off-board or parallel processing, for more accurate, faster operability of the real-time, multi-loop control systems [25]. Non-modifiable on-board processing limits functional flexibility [6], [29], as do the use of external markers for location mapping [1], [35]. Improvements are needed in depth mapping [2] and scale estimation [2], extension into multi-floor environments [28] and 3-D [24]. Inclusion of an Inertial Measurement Unit (IMU) may improve object tracking [2], such as caused by a rapid change of the camera’s Field of View (FoV) [2]. SLAM is implemented in [3] to determine local state estimates from visual odometry and to correct for flight drift; the estimator periodically incorporates position corrections provided by the SLAM algorithm [3]. Trajectory history is combined with sensor data to generate maps for autonomous path planning [3].
The addition of other sensors, such as ultrasonic, stereo cameras or laser, could improve path planning robustness. Leichtfried et al. [1] effectively exploit the GPU processing power for heavy parallelization with emerging mobile devices.

The integration of depth imagery allows for dense 3D mapping and localization in unconstrained indoor environments [1]. The SLAM-based system in [26] can utilize low-bandwidth radio links for communication and is designed and optimized for real-time flight synchronization. UAV size is important: in [27], the small size of the UAV places a frugal payload restriction on weight and power supply. Images from the on-board video are subject to severe vibrations due to helicopter motion which adversely impacts accuracy such as for object/person detection and recognition as extracted from attained video imagery [27]. Despite a lack of embedded, external obstacles in the indoor environment, the drone-based technology developed in [4] is able to effectively avoid collision with surrounding walls. This prototype offers advantage in its custom-made hardware; the drone is small and lightweight, using two processors: one for stability and another for autonomous navigation. It also achieves safe navigation without use of an onboard camera [4].

Monocular SLAM [29] utilizes a similar Parallel Tracking and Mapping (PTAM) as in [2]. Strasdat et al. [30] implement another monocular SLAM technique wherein optimization is used for state estimation and camera projections are used to map the environment. Zhao et al. [33] propose a linear approach to Monocular SLAM by creating large maps from combining a set of smaller sub-maps. CEO-based Fuzzy Logic Controller (FLC) for Fail-Safe UAV has been presented by the authors [6] to expand its collision avoidance capabilities in the GPS-denied environments using Monocular Visual-Inertial SLAM-based strategy. In addition to Monocular SLAM, FastSLam shows promise [31]. This algorithm substitutes the Extended Kalman Filter used in most SLAM algorithms by a less complex, faster method based on tree data structures and a particle filter [31]. Kaess et al. [32] propose an alternative solution called iSLAM, Incremental Smoothing and Mapping, for map generation and trajectory estimation. It utilizes incremental matrix factorization to avoid unnecessary fill-in, in the information matrix. An improved version, the iSLAM2 [34], iSLAM is modified to use graph based incremental matrix factorization; however, there are few notable improvements over iSLAM in regards to speed and complexity in a variety of tested scenarios.

A different technique that uses an RGB-D camera, one with depth measurement, was developed by Huang et al. [3]. This method utilizes a Gaussian pyramid for image processing and FAST feature detector for feature extraction; this data is sent to an off-board computer for processing, producing a map, and loop; closure. An algorithm for quadcopter trajectory generation and flight control, that directly comprises the dynamic restrictions of the quadrotor while executing real-time route planning, has been developed by Hehn and D’Andrea [7]. However, limitations in acceleration and problems associated with dominant aerodynamic effects are not overcome; notably, the vehicle rises when decelerating from high speeds [7]. In addition to providing video feedback, quadcopter camera technologies can also be used for image recognition and processing as well as obstacle avoidance [9, 36]. Vision systems in UAVs enable object detection and object tracking, position estimation, navigation, obstacle detection, autonomous landing, and stable hovering among others [36]. Heng et al. [9] apply autonomous obstacle avoidance by using 3D virtual scans from stereo images.

Obstacle detection and collision avoidance of external objects makes use of an autonomous quadcopter with multiple ultrasonic sensor technology. The ultrasonic raw data is filtered and fused with IMU data, before it proceeds to an obstacle detection module [8]. The collision avoidance module then divides the area around the quadrocopter dependent on the measured distance into three zones: far, close, and dangerous, for each direction [8] and is described as a state machine [8]. Distance to an obstacle is controlled using a PID controller, preventing a further approach to the obstacle [8].

III. FLIGHT CONTROL AND STABILITY

ACO and PID controllers prove most effective for flight control and stability. Cutler, Machine and How [10] introduce an algorithm for navigation of quadcopters based on the principle of ant colonies; mimicking the behavior of small insect congregation, as motivation to create numerous small units that work together to perform quadrotor navigation [10]. He et al. [5] develop a modified version of the ACO algorithm to provide flight path planning for UAV devices, overcoming shortcomings of the ACO algorithm. Their algorithm applies the action of separate ants (with each ant looking for direction) in a colony represented by an array, and then iteratively determines the best path [5]. However, major drawbacks such as slow rendering speed and lack of pheromone guidance cannot be ignored.
PID controllers are effectively applied in [11] to control quadcopter rotational motor speed for system stability. For the tuning of the PID controller, the authors use a 'pole placement method', which is attained by identifying the transfer function determined by the input and output variables of the UAV system that is to be controlled [11]. Research findings reveal the stability of an UAV can be demonstrated through the use of a customized PID controller, to define the pitch and roll movements of the quadrotor [11]. Addition and variation of payload masses to quadrotors and helicopters under PID control is examined in the research [12]. In [13], fundamental principles of dynamics and kinematics are applied by the authors to provide viable control of a quadrotor, to maintain stable, accurate operability when one or more propellers are completely damaged.

A. Discussion and Analysis of Applied Methodologies

2: ACO and Modified ACO: A more accurate version of the ACO algorithm for path planning is explored in [5]. The improvement is in the algorithm solving speed and in the avoidance of local optimum paths. For the base model ACO, each successive ant travels from the origin (ants’ nest) along a path leaving a substance (pheromone) as it progresses. The substance changes over time; a lengthy change indicates an inapplicable route and successive ants attempt new routes. Shorter substance changes suggest a shorter, better path. This process continues until the shortest path is detected through trail that pertains the lowest level of substance change; indicating an optimum path. As described in [5], to apply the ACO concept to UAV flight path planning, the origin of the flight is assumed to be the ants’ nest; the location of origin for all ants. Located in a 3D model with various cells, the first ant treats its current position as the center and then designates a certain path through a random, proportional or pseudo-random proportional rule. Application of these rules results in a solving period of the original ACO that appears to be too slow for effectual results. Additionally, the energy consumption of the UAV vehicle must be taken into consideration.

To address algorithm inefficiencies, a modified version of the ACO is presented in [5]. The modified ACO first assumes that instead of the ants searching one at a time (as in the base model ACO), they search in parallel to save time. An update of the substance left by every ant will not be executed. Instead, the substance left is only upgraded on the best path; the focus of the ant search is therefore on a local optimal path. To avoid the ants reaching the same solution, maximum and minimum levels of the substance released are applied.

Therefore, the difference between an adequate and inadequate solution would not escalate quickly, giving the ants a chance to search along different path solutions. To take into consideration the energy consumption of the UAV, an addition of weighting is introduced to the path length. The modified ACO algorithm promises a faster, more reliable way of finding the best, shortest path for indoor UAV flight, while taking into consideration the energy that the UAV consumes during flight time. The authors [5] suggest further improvements, such as in path smoothing and overcoming boundary concerns associated with the drone’s physical size. Given map data, this is a valid method for optimum flight control. A reliable collision detection and response algorithm is required, in addition to alternative path finding; as it fails to account for environmental changes.

2: PID Control: Research findings reveal the stability of a UAV can be demonstrated through the use of a customized PID controller, to define the pitch and roll movements of a quadrotor [11]. A variety of methods exist for fine tuning a PID controller [11], [13], notably the pole placement [11] and the Ziegler-Nichols methods. Junior et al. [11] present a UAV system with four PID controllers for rotational motor speed adjustment to achieve drone stability; each angle of attitude has a specific PID controller (pitch, roll, and yaw), along with the altitude. PID controller fine-tuning is enabled through allotment of sets of open-loop poles into the appropriate (corresponding) closed-loop pole locations, creating the transfer function of the closed-loop system with the basis of the system’s open-loop and PID controller transfer functions [11]. The transient performance specifications of the UAV are therefore proposed through constraints by the transfer function. Translation of the open-loop poles into closed loop-poles is then realized with the Diophantine equation whose solution gives the values for the PID gains [11]. There is scope for further fine tuning of the PID controller in [11] for greater dexterity.

The Ziegler-Nichols Method enables two options for PID controller tuning [37]. The first method examines the response of a plant to a unit-step input [37]. If the response of the plant is an S-shaped curve, both the delay time and the time limitation set by the user are deduced through a tangent line drawn to the point of inflexion the turning point of the response curve [37]. The transfer function of the plant’s response to the unit-step input is then computed [37]. PID controller constants $K_p$, $T_i$, and $T_d$ are then derived.
The second method is achieved through setting the initial time at infinity, and setting $T_d$ to 0, and increasing $K_p$ to $K_{cr}$, where the output would contain sustained oscillations in a closed loop system. The values of the variables $K_p$, $T_i$, and $T_d$ for PID controller are then computed, using $P_c$ and $K_{cr}$ values. The Ziegler-Nichols method is widely used and accepted for PID controller fine tuning [37]. In the event of UAV damage, data feedback in conjunction with a nonlinear control algorithm implemented, allow the user to continue to maintain a certain height of the quad-rotor’s hover flight despite completely damaging one or more propellers [13].

IV. VOICE RECOGNITION AND NOISE SUPPRESSION

VR and SR are examined in the literature to control robotic devices [14] to [19], [38]. SR hardware solutions [16] to [18] and novel algorithms [14] to [17], [38], [39] are proposed in the research in real-time robotics, such as in Air Traffic Control (ATC) [18], [19] and towards the investigation of the use of natural language communication commands to drive robotic movement [16]. Data transmission between user and Automatic Speech Recognition (ASR) equipment are investigated in [17]. SR is applied in ATC systems [18], [19] and ground-restricted robotics [16]. However, these types of algorithms are lacking in UAV applications.

Approaches to overcome challenges of SR in noisy environments and the reduction of signal interference were examined [39], [40], with modified versions of the Hidden Markov Model (HMM) applied extensively in the research [15], [38], [39] and Neural Networks (NNs) for voice signal classification [14], [17]. In addition to problems associated with signal interference in a noisy environment, two major challenges in VR are word recognition within an extensive vocabulary and words with similar phonetics [19]. HMM is effective in SR, combined with NN in a hybrid configuration that works on the principal of word-sound correspondence [19], as applied in [15] and [17]. Class-based and dynamic language models are presented in the literature: the former sorts words into classes based on their morphological and semantic features [17], while the latter considers the degree of recurrence of the word in the recorded history of usage to identify input keywords [19]. Jose et al. [18] propose an ATC SR model for ASR and controller event detection, enabling automated analysis and interpretation of ATC voice interactions. Input recordings are taken by a VoIP recording system. A hardware and software solution is implemented by Shafkat [16] for real-time user-robotic interactions via SR resulting in robot motion through user initiated commands.

Algorithms for Voice Activity Detection (VAD) are compared in a survey describing a variety of assessment structures that process speech signal information [23]. Methodologies applied include: Long Term Spectral Divergence (LTSD), Multiple Observation Likelihood Ratio Test (MO–LRT) and order statistics filter (OSF) [40]. LTSD utilizes a long-term speech window to track the spectral envelope of the speech so that a decision rule can be formed between the speech and noise [40]. MO–LRT aims to improve the decision rule through the incorporation of several observations to statistical testing [40]. OSF applies Multiband Quartile Estimation (MQE) Signal to Noise Ratio (SNR) to improve difference in speech caused by fricative sound through the complementary information it gives [40]. Mohamed et al. [39] examine two models for the analysis of SR systems in noisy conditions, aimed at stacking the elements of clean and boisterous channels to form a new, enlarged space comprising measurable models of a SR system. These factual models are interpreted for the prediction of the clean speech components from the noisy feature set. Shanthi and Lingam [15] apply HMM for SR, with algorithm enhancement using the Forward, Viterbi and Baum-Welch algorithms. The process of SR involves feature extraction and feature matching, where each word in the vocabulary has a distinct HMM that acts as reference for subsequent word matching [15].

The Mel Frequency Cepstral Coefficient (MFCC) enables processing of a digitized voice signal through pre-processing, Framing, Windowing, DFT, Mel Filter Bank, DCT and Delta Energy and Spectrum analysis, to extract voice features which are then sent to a Dynamic Time Warping (DTW) algorithm that selects the corresponding pattern from a reference signal in the database [38]. While MFCC and DTW methods are applied in an environment that lacks noise interference [38], a filtering system for SR based on a Fuzzy NN is proposed for background noise suppression, in [14]. The application, G.H.O.S.T, is developed for the purpose of providing elderly and handicapped individuals in a smart home environment [14]. Another system designed for disabled citizens uses NN classifiers for VR to improve SR by the reduction of False Acceptance Rates (FARs) of keywords in voice-driven commands [17].

Systems offering acceptable speech detection rates for real-time applications are lacking [18]. However, results from the research show promise in efforts to address this deficit; in ATC voice communication, Jose et al. [18] achieved an event detection rate (EDR) of around 70% in both flight en-route and approach communications.
HMM approaches reveal utility for word detection and classification [15]; algorithm modifications are proposed to overcome errors in evaluation, decoding and optimization of model parameters for voice signal sequence processing [15]. MFCC combined with DTW for word extraction in the presence of background noise proved effective in the study conducted by Vanus et al. [14], even if the voice signal is highly distorted. Compared with classical HMM and the DTW technique, the NN classifier proposed by [17] reveals accuracy of classification and speed. An Adaptive Neuro-Fuzzy Interference System revealed an improvement in error rate for real-time speech processing in a noisy environment, in comparison to the Least Mean Square (LMS) algorithm, in a series of tests conducted by the authors [14] using wired and wireless microphones to capture speech input subject to ambient noise.

A. Discussion and Analysis of Applied Methodologies

SR algorithms and applied technologies, such as in the areas of robotics, are designed for voice processing, subsequent decision making [15], [16], [38], real-time applications related to ATC [18], [19], [39] and conversion of speech signals into control codes [13]. Challenges for design and implementation of current methodologies include noisy input voice signals and continuous speech detection [38]. Through his literature review, Shafkat [16] identifies required constituents of such a system to include a robotics module and active SR components, integrated and with the ability to initiate and interactively control robotic movement through speech-driven commands. Vanus et al. [14] propose a background noise suppressor based on Fuzzy NN to minimize noise in the SR system. In order to match a voice signal with a keyword in a database whilst minimizing classification error, speech processing using MFCC is used in [38]. Ramirez et al. [40] apply VAD to obtain high speech coding, low bit rate transmission and improved speech communication. In addition to VAD [40], Gaussian Mixture Models with SSM and SHMM proposed by Mohamed et al. [39] will be adapted to decrease word error classification rates in the presence of noise (due to propeller rotation). Although HMM faces issues in the evaluation of hidden state determination and learning, the Forward, Viterbi and Baum-Welch Algorithms presented by Shanthi and Lingam [15] may be applied to overcome these challenges.

V. DECISION SUPPORT FOR PATIENT HEALTH STATUS

Rule-based expert systems, systems that rely on NN classification and/or decision tree logic have been designed for dedicated clinical care [20] to [23]. MYCIN applies a rule-based system to diagnose and recommend treatment for blood infections; assisting clinicians in their choice of antibiotics for bacteremia or meningitis. Clinicians enter information regarding patient history, physical findings and laboratory results into the system, which then provides patient-specific recommendations for antibiotic coverage [22]. INTERNIST-I is a rule-based system that uses observations of patients to classify various states of disease [20]. INTERNIST-I was initially designed in 1974 and links diseases with symptoms using a tree-based structure that performs a complex diagnosis for general internal medicine. ONCOCIN applied a customized flowchart language for the implementation of a rule-based medical expert system with an aim to assist physicians in the treatment of cancer patients receiving chemotherapy [21].

A. Discussion and Analysis of Applied Methodologies

Accuracy and applicability of computerized, real-time DSS’s in clinical care for mental and/or physical healthcare require further research toward algorithm development and improved research results. Only 69% of the cases diagnosed with the help of MYCIN proved successful, however this performance was superior to human expert results for classification of infectious diseases [22]. In practice, MYCIN was never widely used due to difficulties with maintenance and incorporating the system into a clinician’s workflow. INTERNIST revealed promising classification accuracy, however the long processing times render it impractical for real-time response; requiring 30-90 minutes on average per consultation [20]. INTERNIST successor systems included Quick Medical Reference (QMR) and although results improved, QMR analysis proved successful in only 72% of clinical cases [20]. In another study investigating how well DSS’s work at responding to a bioterrorism event, an evaluation of 103 consecutive internal medicine cases revealed a classification accuracy of only 73% [23]. Hence much research is required into the design of an accurate DSS for clinical healthcare and for a fully automated drone-based DSS.
Fuzzy NNs [14], [17], rule-based expert systems [21], [22] and decision tree classifiers [20] reveal scope to develop a novel, more accurate intelligent, server-side medical DSS for real-time response.

VI. CONCLUSIONS AND FUTURE WORK

Limitations in current solutions reveal scope for research work, addressing the challenges of flight control, stability, obstacle avoidance, patient detection and classification, real-time communication between drone and server, VR analysis, and development of a customized artificially intelligent DSS to action healthcare requirements, in an indoor environment. Whilst the extensive literature addresses some of these challenges, independently and collectively there is no workable, research solution established. Future work considers the hardware and software solutions as a platform to develop and extend the research in this field. SLAM and ACO algorithms show promise for flight path planning. These methods, combined with customized PID control and optimization such with pole placement and Ziegler-Nichols methods, show promise for autonomous flight navigation, collision avoidance and UAV stability. For obstacle avoidance, a combination of ultrasonic sensors and cameras seem to provide the most effective hardware combination. Enhanced VAD and HMM strategies for VR, combined with Fuzzy NNs, rule-based expert systems and decision tree classifiers will be designed and developed to provide an accurate, intelligent DSS for drone-based patient healthcare in the home; toward independent living and emergency management.

REFERENCES


