One of the challenging problems for the design of human-machine automation systems is that human operators are either kept 'out of the loop' by adopting excessively high level of automation or, when human-centered manual control paradigms are used, vulnerable to performance breakdown or prone to errors especially in the conditions of high workload, taskload, or mental stress (strain). To cope with this problem, the strategies of adaptive automation (AA) can be utilized, in which tasks in question are switched dynamically from human to computer (machine or complex technical systems in general with which the human operator is interacting) when vulnerable operator functional (e.g., physiological and behavioral) states (OFS) are detected.

Nevertheless, in currently-scattered literature in this emerging field, most existing AA systems have used only human operator performance and task models and have not been successful in demonstrating performance improvement. It will be shown by this talk that overall human-machine system performance can be improved and adaptive automation can be achieved by monitoring human Operator Functional States (OFS) based entirely upon multiple physiological and performance measures.

A series of intensive laboratory physiological (i.e., brain and cardiac responses) and performance data collection experiments and their analyses were performed using a total of 11 student operators on a simulated complex, safety-critical decision-making and process control task platform involving the management and regulation of a total of five subsystems within the allowable range around the prespecified setpoints. To design an appropriately controlled experimental procedure, a novel 'cyclic loading' technique is proposed, in which the task load, namely the manual control load which is represented by the number of control subsystems (i.e., the key controlled variables) requiring manual control, is elevated in a stepwise fashion until breakdown of the system performance occurs. This technique enables us to test and determine the critical risky (or strained) OFS immediately prior to the occurrence of performance breakdown.
The measured data were then used to construct two types of adaptive fuzzy models for the high-risk OFS of individual volunteering operators. The selected structures of all the OFS models (11 in total here) contain a common and fixed number of input and output variables, which were determined \textit{a priori} by means of trial-and-error (or enumerative) comparisons of simulation results obtained from different combination of I/O variables. The most dominant (or significant) indicators (or features) of risky OFS, which are most sensitive to the systematically controlled variations in the level of manual control taskload (somehow intimately related to the mental or cognitive stress undergone by the operators performing the tasks in the experimental sessions), were thus determined as two sorts of physiological variables including EEG task load indices (TLI) and heart rate variability (HRV). As the personalized model for each operator is entirely based on the individual-specific data, the generalization (or prediction) performance (of main interest and concern in the present investigation) of both adaptive fuzzy models were shown to be very promising in extensive simulations on the complex process control task platform.

In summary, the major contributions reported in this talk include:

- Some novel signal processing and pattern recognition, especially feature extraction, methods were developed to improve the quality and usefulness of physiological signals such as cardiovascular and electroencephalogram (EEG) responses.

- Two types of adaptive fuzzy models were developed and validated to accurately assess the OFSs using the measured physiological signal data. The developed techniques are superior to the artificial neural networks and linear system methods introduced in the existing literature in their higher modelling accuracy. The intelligent system based modelling techniques presented here are also more robust and reliable in terms of their ease of practical use as well as applicability to a range of individual human operators.

At last, the talk will briefly discuss the practical implications of the measured physiological data and the proposed intelligent models of OFS as a feasible, effective and universal approach to implementing the concept of AA of human-machine systems. Naturally from this methodological perspective, as an essential part of future work along this line of research, an adaptive control interface will be developed by using the logic and strategy of AA for final implementation of online closed-loop control system.