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Evolution of ICT for the Improvement of Quality of Life

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INTRODUCTION

In today's society, *chronic diseases* are a well-known issue related to the average increasing age of a population, especially in the most developed countries. The elderly, who are often the most impaired individuals, experience a significant reduction of independence in their daily life. This, consequently, affects their psychological conditions as well as their social attitudes and relationships. Therefore, industry, academia, and government health organizations are actively investigating and testing large-scale affordable solutions to improve the overall *Quality of Life* (QoL) in this population.

QOL DEFINITION

QoL can be defined as an "individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns" [1]. In other words, "QoL is a subjective, multidimensional concept, which places emphasis on the self-perception of an individual's current state" [2].

Surveying among a large and heterogeneous population all over the world, the World Health Organization (WHO) identified several domains that generally determine satisfaction about health-related QoL (HRQoL). Not only physical conditions are included, but also psychological, social (independence and relationships), and environmental (climate, crime rate, landscape) ones seem to be important [3], [4].

As suggested by Frow and colleagues [5], it is possible to create a *Health-Related Ecosystem* that could be characterized by four levels: the *Micro level* includes the individual patient, the clinical staff, as well as his/her family and friends; the *Meso level* includes clinics, hospitals, and also other health agencies; the *Macro level* includes State health authorities, professional associations, Unions in health care sectors, and Health insurers; finally, the *Mega level* accounts for Government agencies, health funding bodies, regulatory bodies, and even media.

Based on a framework such as this one, a *Health Care Business Model Ecosystem* (HCBMEs) can be developed to optimize the cost-benefit tradepff in terms of HRQoL. Specifically, HCBMEs typically account for vertical and horizontal markets, including all possible stakeholders and operating within the healthcare framework. HCBME evaluates telecare-related HRQoL both in terms of its economic burden, i.e. financial resources for specialized personnel, infrastructures, spaces in the public institutes, and social inclusion (avoiding problematic situations, e.g., elderly isolation). Optimization through HCBMEs could mitigate issues like long waiting lists, suboptimal admission criteria, bed-blocking, multiple diagnoses, all delays experienced in current clinical practice (impact on the Micro and Meso levels), while minimizing costs for hospitals and State health agencies (impact on the Meso and Macro levels).

It has to be noted that healthcare in different countries is supported by different organizations, either the national health system (such as in Greece, Italy, Nordic Countries, and United Kingdom) or national social insurance system (such as in Austria, France, Germany, and The Netherlands). At the same time, the social welfare system is usually regional or locally-based. Therefore, the modalities of how healthcare can be accessed in different places are subject to different rules and constraints. Availability of services can differ as well. The HCBME concept also give insights and suggestions about how to coordinate different healthcare providers in order to overcome inefficiencies, ensure interoperability between different countries, and reduce overall costs for health, ensuring at the same time a high quality and uniform level of health-related service.

The recent concept of *Internet-of-Things* (IoT) can be applied to the healthcare ecosystem (IoT-health) to provide a framework where everyone is connected and connections and communications can be achieved both within-levels and between-levels of the HCBME [6], [7]. This futuristic ecosystem scenario is made possible by the technological developments across disciplines within a multidisciplinary area involving all actors of the *healthcare ecosystem* [8], including the patients and medical doctors (micro and meso levels) and the communication providers and insurance companies (macro and mega levels) that provide different kinds of services to the core actors. IoT-health is expected to optimize resources within the HCBME and the HRQoL.

Specifically, IoT-health needs to focus on the diseases that impact the most people in the HRQoL. The abovementioned survey by the WHO classified the most impacting diseases in our current society as in *Five Big Chronic diseases*: diabetes mellitus, cardiovascular disease, chronic respiratory disease, cancer, and stroke. It may also be useful to include Alzheimer's (AD) disease and Parkinson's disease (PD), as well, because of their long-term effects on patients and the need for continuous monitoring. That said, we can then label them as the *Seven Big Chronic diseases* (7BCD) of our society.

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In order to provide HRQoL to these specific pathologies, different needs have to be taken into consideration and manifold solutions have to be designed to support patients when dismissed from hospitals. Specifically, it is possible to identify a number of *assistive domains*, i.e., domains where continuous support is needed for patients living at home, together with the most suitable technological solutions. The most relevant domains for the 7BCD can be distinguished as follows: mobility, drug adherence, cognitive training, physical training, entrainment and social inclusion (socialization), pervasive monitoring (Table 1).

Digging into the specific needs of each pathology is beyond the scope of this article. However, *pervasive* monitoring, or comprehensive ICT-based continuous monitoring of a number of different aspects of the life and the health of the patient (both in time and in space) is a developing technology with lots of potential for the health industry. Indeed, the literature has already provided evidence on the importance of capturing small (daily) changes in the habits, as well as in the health conditions (sleep, gait and so forth) of a patient that can be recognized as proxies of arising pathologies, such as AD or PD. At the same time, this kind of wide and continuous assessment can bring significant insights on the disease progression.

Apart from its potential benefits for the HRQoL, the above-mentioned technology-based continuous monitoring solution has opened several ethical issues related to a patient's compliance with technology, security, and privacy, given the large mounts of data acquired and remotely transmitted .

Therefore, HRQoL can be viewed as a complex and multidisciplinary *ecosystem* where different stakeholders are interacting with each other, infrastructures are increasingly deployed, and services are constantly required to be improved with new customized features. This framework definitely needs regulation for ethical issues as well as interoperability and standardization to achieve optimal solutions that can improve the *individual-HRQoL* with minimal organizational burden.

ICT SOLUTIONS FOR HEALTH

Many of the recent ICT solutions in health-care have the goal of achieving improvements in health monitoring and intervention, on one hand, and making low-cost devices massively available, on the other hand.

ICT solutions can be included into the manifold *communication-navigation-sensing* (CONASENSE) framework because sensing devices and related signal processing are needed to acquire and locally process biomedical data coming from the cooperating individual; suitable communication technology is needed to efficiently transmit such informative (mostly, compressed) data to the main servers or to a central database for long-term storage and further processing; and navigation mechanisms and technologies are used to track individuals when health-related services are provided in a mobility context.

In the following sections, special focus will be given to (1) the state-of-the-art of communication and navigation solutions, (2) the most recent sensing devices and, finally, (3) the most up-to-date signal processing techniques.

COMMUNICATION/NAVIGATION

The typical scenario where communication and navigation technology are involved is represented by three main networks: (1) the

Table 1.

Association between *Assistive Domains* with the *Seven Big Chronic Diseases* (7BCD) of Our Society

Domain/7BCD	Diabetes	CVD	CRD	Cancer	Stroke	AD	PD
Mobility	X	–	–	–	X	–	X
Drug Adherence	X	X	X	X	X	X	X
Cognitive Training	–	–	–	–	X	X	X
Physical Training	X	–	–	–	X	–	X
Socialization	X	X	X	X	X	X	X
Pervasive Monitoring	X	X	X	X	X	X	X

body area networks (BAN), (2) the personal area networks (PAN), and (3) the local and wide area networks (LAN and WAN, respectively).

BAN are generally made by the integration between different kinds of sensors that are located in-, on-, or nearby the individual's body. These networks are intended for the acquisition of the big and heterogeneous data from the person in his/her daily environment. Therefore, mobile and heterogeneous devices need to be deployed and integrated with each other.

PAN typically includes hubs and fixed gateways for the transmission of data from one or more BANs to a central server that is required to store data for further processing or to keep a database of patient's health records.

Finally, LAN and WAN represent the typical wireless infrastructures which telecare systems can exploit to establish remote communications. By construction, LAN and WAN include many different links, devices and users; therefore, coordination and synchronization between them are required at the platform design stage.

From a technological point of view, the homogeneous integration of the three areas (BAN, PAN, LAN) and the seamless transition between BAN and PAN remains one of the most challenging task to cope with [9].

Indeed, many proprietary technologies as well as international standards (ZigBee Health Profile, Bluetooth Low Energy, Low-Power Wi-Fi built on the top of IEEE 802.15.6), exist to implement such kinds of networks: however, interoperability remains a big issue among different networks employing them. Moreover, most international standards were not specifically built for telecare, but they are rearrangements of other standards, originally created for different purposes, e.g. Bluetooth among others. Interoperability and integration between different standards could be fostered by the establishment of standardized data formats for data exchange among different telecare systems as well as different parts of the LAN/WAN network. On the other side, the identification of devices within the network or new devices joining it is of fundamental relevance in order to have a scalable and flexible network. Therefore, *Independent Living Hub* device specialization defined equipment as well as physical environments, e.g., “toilet”, “microwave”, and so forth, through unique classification. Similarly, the family of standards named as *ISO/IEEE 11073 Personal Health Data* provided standardization of data format and device types, regardless the underlying technology [10]. Interoperability issues arise also from the use of different RF spectrum ranges by different communication protocols and, on the opposite, from the interference caused by competing protocols implemented on the same frequency band. Among others, 802.15.4 and 802.11 technologies operate on the same industrial, scientific and medical band (2.4 GHz) causing interferences between each other [9].

Moreover, while BAN and PAN are typically geographically confined within the residential space, i.e., they are fixed in the space, individuals wearing BAN sensors most often move away from the PAN area (e.g., elderly spend about 25% waking hours up to 60 km away from their home). Therefore, suitable technology for mobile telecare has to be employed and smooth transitions between different networks have to be efficiently implemented. Often, Global System for Mobile Communications (Short Message Service) or GPRS/3G in combination with Global Positioning System (GPS) are used to provide telecare services and localize the elderly in case of emergency. Another solution could be represented by the deployment of hotspots, as much as in the cellular networks where they are successfully used. To the same regard, international workgroups have started to suggest solutions: among others, the paSOS protocol aims to provide a seamless transition between network architecture of BAN/PAN (geographically limited) and network architecture of LAN/WAN (mobile networks) using a standardized format for data exchange between mobile devices and a remote service [11].

Finally, the next generation, fifth generation (5G) wireless communication will be available, providing important features: low-energy consumption, high data rates, and very low latencies, especially. These will make it possible to implement new generation telecare systems and to expand the market for such kinds of systems, with consequent costs reduction and impact on a larger population. This will further increase the individual-HRQoL and it will bring hospitals and research centers to collect big data, easily, for a more reliable predictive analysis on pathologies and health conditions.

SENSING

The dramatic evolution of nanoelectronics allowed the development of a brand-new generation of sensors which can be used for pervasive monitoring of individuals with health-related needs while living at their homes a near-independent life.

This new kind of sensors can be very tiny and unobtrusive, such that they can be easily located either in-body or on-body.

There are two main classes of health-monitoring sensors: the first includes *wearable sensors*, which can be placed over the skin or embedded into clothes or other accessories, such as smartwatches and elastic bands. The second class is represented by *implantable sensors* for measuring critical vital parameters with higher precision. Typical examples of such kind of devices are the biosensors that measure levels of metabolite in the blood of diabetic patients, and pacemakers for cardiovascular disease patients.

Sensors can be also classified into passive and active. Specifically, passive sensors are used to measure a set of parameters, to locally process them, e.g. apply compression, and to send them either to a central hub or a main server for alerting caregivers and the medical staff on any vital value beyond some safe range. At the same time, passive sensors may regularly transmit data to a central server to store them for further detailed processing. On the other side, active sensors can be used to provide specific real-time actions to interrupt an emergency and give relief to patients, while alerting the medical staff about the critical event. This kind of automatic intervention is called as *closed-loop system*. The very first example of active sensor for vital sign recordings with real-time closed-loop intervention was the *pacemaker*. A pacemaker is a small device that is located either in the chest or in the abdomen to help controlling the abnormal heart rhythm in patients suffering from cardiovascular diseases. Since 1872, when Green showed that an electrical impulse could trigger the heart to recover its normal heartbeat rate, when abnormally stopped [12], the development of pacemakers moved from the use of alternating current-powered vacuum tube electronics to current solutions using microelectronics and lithium batteries. Similarly, small automatic pumps for insulin injection are available for patients suffering from diabetes.

While the spread of very sophisticated implantable sensors, e.g. pacemakers and insulin pumps, is limited by costs, invasiveness, and recipient patients, wearable sensors are seeing a sudden growth in their market, where both patients and healthy subjects (especially in the sports) aim to intensively monitor their own health conditions. This is due to their low-cost, large-scale availability and noninvasiveness that give people the capability to be aware of their own health or sport performance and to take actions to improve them. Therefore, smartwatches, smartphones, and wearable straps and bands provided with accelerometers, pulse oximeters, simple heart rate monitors, as well as GPS and other simple sensors for track vitals, are becoming more and more popular. It is interesting to note that, while at the beginning low-cost wearable devices were mostly employed to improve performance in sports by healthy individuals, more recently, they have been included in the most advanced tele-monitoring platforms addressing a large and heterogeneous population of patients, gaining attention and founding by several founding agencies all around the world.

Nevertheless, sensing has recently come with issues related to interconnection between sensors: they typically communicate via wireless links characterized by a specific topology and communication protocol, depending on requirements and constraints of the particular application.

At the same time, sensors are devices able to acquire data as well as perform computations: mostly, a trade-off between centralized and distributed computation has to be taken into account.

Nowadays, the hardest constraint is given by the batteries duration inside devices: some of them last for hours, others need to survive in a continuous-mode operation for days and months (invasive devices are required to prolong their life to few years). There are many factors that could influence the duration of batteries: mode of operation, local processing, and communication protocols. Indeed, *bursty* (infrequent and short-time) or continuous mode of operation could be easily seen as one of the most important parameters to evaluate when design such a tele-monitoring system. At the same time, compression and local aggregation of data could represent a necessary step to be locally performed at the individual sensor level, while more demanding signal processing could be assigned to main hubs or central servers (typically supplied with *unlimited* power). Finally, the particular topology of the sensors infrastructure, as well as the energy resources needed to implement the communication protocol within-network and between-networks, could be further consume battery energy.

Therefore, intense and dynamic research has been ongoing for scavenging [13] and harvesting energy from alternative resources, e.g. capturing energy from the ambient, as well as from the human body itself (through its movement or the gradient of temperature over its surface).

To this purpose, environmental sensors could be also added to the network, in order to gather measures such as the ambient temperature, the humidity level, the wind strength (if outdoor), and so forth. This information could be then complement for the vital sign measurements in order to provide a comprehensive (quantitative) picture of the living conditions of patients and athletes.

Overall, the mainstreams of academic as well as industrial research focus on the development of efficient communication protocols (5G), unobtrusive hardware design as well as smart data analytics to prolong the battery life of sensors within the network (IoT,), thus providing a pervasive and customized monitoring environment to improve the QoL.

ANALYTICS/SIGNAL PROCESSING

Signal processing for HRQoL generally labels a set of software tools which deal with the transformation of data into different domains, e.g., frequency, compressed or others, performed at the sensor level, at a central hub, e.g., in a star-topology network, or offline to carry detailed and smart analysis. Typically, three possible kinds of data are involved in a system providing HRQoL: biosignals, event information, and multimedia [9].

Biosignals can include vital signs and other signals such as the electrocardiogram (ECG or EKG), the electromyogram (EMG), and the electroencephalogram (EEG). They are usually recorded by dedicated instrumentation, but low-cost and portable solutions are currently available to perform some rough, but still useful, measurements. They all include a differential measurement of the potential difference between one location, i.e. point of interest, and a reference location (typically, selected to be located nearby). ECG, EMG, and EEG, as well, allow for a multichannel recording, that is, multiple sensors are placed over the chest, the skin, and the scalp of the individual, respectively, and signals are acquired in a synchronous way from all available electrodes, simultaneously. This gives tremendous advantages on the way to investigate abnormal behaviors in details and to extract the most explicative (even complex) features to synthetize the individual's behavior or health condition.

Event information includes emergency alarms, fall detections, and other bursty data traffic that could be generated at specific time instants (mostly, infrequently). They allow caregivers and the medical staff to promptly provide intervention to cope with any emergency or to collect such kind of data for further processing.

Multimedia can embrace a large variety of data, mostly multidimensional and continuously recorded over time, such that three-dimensional images from imaging (magnetic resonance imaging, positron emission tomography scans, and radiology), video or VoIP, but also gait over dedicated sensorized paths as well as virtual reality for augmented experience of reality.

Processing of all such data could be performed into two very different modes: (i) real-time and (ii) offline.

The first is typically implemented in case of closed-loop applications and alarm delivery systems that require low computationally demanding and (generally) coarse features to be extracted, within very short time lapses. Fast and low-demanding signal processing may also include compression at the sensors level as well as data aggregation at the hub or at the central server level: compression and aggregation can contribute to lower the energy demanding of the network (communication protocols) and to prolong the life of sensors battery and, ultimately, of the network itself. Indeed, IoT for health and the most advanced 5G communication technologies are been developing to address such kinds of challenges: specifically, the IoT framework will allow smart objects (not limited to sensors) to communicate each other, while 5G will provide services at very low-latency, i.e., close to real-time, with minimum power consumption (and maximum battery life).

This extensive data exchange will arise issues regarding authentication and protection of data, most often sensitive patients' data. Suitable strategies still need to be designed and implemented: work has been already done [6], with encryption standards developed on purpose; however, the most challenging question deals with the policy for keys distribution within the network and at the moment when a new node joins it. A recent and promising solution has been suggested by [7] where common encryption key distribution is complemented with authentication using much richer information from (some) physiological signal. Standards (national, as well as international) are also needed to allow access to data stored in the clinical databases: access authentication as well as privacy of patients need to be ensured.

The second kind of processing could take longer time to be completed and, as such, a more detailed analysis could be carried on. Nowadays, the most popular approach (or research direction) is to acquire *big data* from a large number of sensors and to process them using smart artificial intelligence algorithms, e.g. *deep learning*, above all. This allows to take a comprehensive set of data, i.e., highly descriptive, into consideration to investigate on the current patient's health conditions. At the same time, such advanced analytics on very large dataset, possibly longitudinal, can be helpful in shedding light on the development and progress of highly impacting diseases, such as the 7BCD.

Prediction models as well as analysis on comorbidities could be developed with advantage for today patients as well as for the generations of the future. Indeed, literature showed how slight changes in habits and vitals of elderly could be recognized as proxies of arising pathologies, like AD or PD. Deep learning and other advanced machine learning algorithms can strongly help in modelling a normal behavior and detecting those abovementioned tiny changes, despite the high intersubject and intrasubject variability inherently present within any biological data.

Quantitative biomarkers for the aforementioned changes should be identified in the large available datasets and can be used (i) to reduce the number of individuals suffering from chronic pathologies in the future (*preventive medicine*), (ii) to design the most suitable clinical intervention for each individual patient (*precision medicine*) especially in case of closed-loop applications and, finally, (iii) to reduce the global healthcare-related costs (HCBME).

MEASURING ICT-BASED HRQOL

As mentioned in the previous sections, ICT can be expected to provide benefits in terms of patients' satisfaction, improvements in their physical, cognitive, and social abilities [14], as well as for the reduction of the economic burden for hospitals and State health organizations.

Nevertheless, such benefits have hardly been measured in a reliable way, due to the complexity of the health-related ecosystem involving four levels of stakeholders, a manifold domain characterizing the patients' conditions, as well as the lack of standardization of the technology used in the ICT-based solutions for health.

Before to evaluate the impact of the ICT on HRQoL, a significant effort is required to provide reliable tools for evaluating the HRQoL itself. Up to now, only *qualitative* methods are available. The most important tool for such evaluation has been developed by WHO few decades ago. Indeed, in 1991 WHO formed the *WHO-QoL workgroup* with the aim to provide a definition of QoL and to design tools for its quantification. The WHOQoL workgroup supplied a comprehensive and cross-cultural questionnaire, the *WHOQoL Questionnaire*, which included questions spanning a large variety of well-being attributes [1]. The questionnaire was self-administered to a large population of individuals, including people suffering a variety of diseases, experiencing different severities of illness, and belonging to several cultural subgroups. The well-known five-point Likert scale was used in the questionnaire to quantify the relevance of selected domains scanning all the aspects of the human life, both in healthy and pathological conditions. Either four or six domains summarized the physical and psychological health of the individual, the level of independence, and the quality of his/her social relationships, together with other broader aspects, e.g., the environment characteristics, and even the personal spiritual conditions [15]. Incidentally, despite its qualitative characterization, literature assessed a good validity and reliability for the WHO Questionnaire, afterwards [2], [16], [3].

Following the WHO experience, other works provided other parameters how to quantify the QoL in a large variety of individuals. For example, Walter and Schlapfer [17] identified 71 different amenities that could contribute to well-being. Among others, labor, housing, education, quality of public goods, healthcare services, remoteness of facilities, but also crime rate and crime protection, attractive landscapes, urban development, and atmospheric emissions have been included in the list.

Interestingly, specific outcomes related to health and disease-specific were developed, also: the HRQoL and the disease-specific HRQoL were tested on different populations, both in case of patients and caregivers, with particular attention to “dimensions commonly omitted from other generic QoL measures” [3], [4].

Despite the accuracy and the detailed analysis yielded by the WHO-QoL workgroup and the HCBMEs, the quantification of HRQoL still remains a challenge. The broad range of attributes and circumstances to be taken into account, as well as the rapid evolution of the society and the social and historical context (“country in transition”, see [18]) make it difficult to concisely quantify the HRQoL. Not least, the frenetic development of ICT is deeply pervading our life, inducing further complex changes in the society behavior.

Therefore, in the try to measure the impact of ICT on HRQoL, ICT itself is found to strongly influence the individuals' behavior: thus, methods for evaluating the manifold aspects of the HRQoL ecosystem must be needed.

Besides, IoT-health is expected to significantly improve the HRQoL; nevertheless, key features such as interoperability, security, and system integration [19] have to be ensured in order to reduce the overall costs for IoT-health services and to allow the spread of this new generation ICT-based healthcare.

Table 2.

Positive Outcomes of ICT-Based Intervention on the *Five Big Chronic Diseases* of Our Society (Extracted by [21])

Outcome [%]	Diabetes	CVD	CRD	Cancer	Stroke	Overall
QoL	—	8	2	2	1	13
HRQoL	2	1	4	1	—	8
Mediation adherence	1	1	1	—	—	3
Clinical outcome	1	5	3	0	2	12
Cost efficiency	3	4	2	2	—	11
Time efficiency	1	1	—	0	0	3
Less hospitalization	1	1	7	1	4	2
Technical usability	1	2	1	2	—	6
Satisfaction	2	2	2	1	0	8
Safety	—	1	0	1	0	2

NOTE: Percentages refer to patients of a specific disease (columns two to six), while "overall" outcomes percentages have been computed on the entire available sample of individuals. Rows two to five account for health-related outcomes, rows six to eight for organizational outcomes, rows nine to eleven for technical outcomes.

Despite the strong impact that ICT is expected to bring on healthcare, a measure which can robustly account for its benefits for the HRQoL is still lacking [20]. However, in a recent study by Wildevuur and colleagues [21], a systematic survey from three large databases (the Cochraine library, PubMed, and EMBASE) showed that telemedicine systems e.g., personalized ICT-based platforms, could provide both an increase on disease-specific *clinical outcomes* and beneficial impact on *organizational outcomes*, such as a decrease in hospitalization and an increase of cost efficiency (see Table 2 with some selected outcomes reported).

CONCLUSIONS

Quality of Life (QoL), and particularly health-related QoL (HRQoL), can be defined as a multidisciplinary area of research, industrial development, and healthcare that aims to achieve satisfaction in the daily life of people, especially elderly and patients.

Information and communication technology (ICT) represents a promising framework that could strongly help in achieving a large-scale solution for the improving HRQoL. Indeed, recent advancements in nanotechnology (sensors miniaturization), communication and network protocols (5G and IoT) as well as smart analytics (machine learning) could push far forward healthcare, reaching an increasing number of at-risk individuals, reducing, at the same time, the health-related costs that hospitals and healthcare institutions have to sustain.

The main future directions for improving ICT-based HRQoL strongly rely on the integration of different solutions and expertise, with the concurrent standardization of technologies and protocols among different health service providers. Finally, the construction of a proper global healthcare ecosystem business model could reliably evaluate the impact of ICT onto HRQoL, both in terms of clinical outcomes and economic sustainability. ◆

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IMPORTANT - Please indicate clearly the post applied for (i.e. Assistant/ Associate Professor in Space Technology) when submitting an application or inquiring about this job announcement.

To apply, please refer to the Guidelines for Submitting an Application for Faculty Appointment: (http://www.ntu.edu.sg/ohr/career/submit-an-application/Pages/Faculty-Positions.aspx) and send your application (cover letter and a full CV) via email to:

Chairman, School Search Committee
c/o School of Electrical & Electronic Engineering
Email: EEE-Fac-Recruit@ntu.edu.sg

Electronic submission of applications is encouraged. Only shortlisted candidates will be notified.

Application Deadline: Position is open until filled.

www.ntu.edu.sg

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