

SYSIASS – an intelligent powered wheelchair

Annemarie Kokosy

ISEN
41 boulevard Vauban, 59046 Lille, France
LAGIS – SYNER team
annemarie.kokosy@isen.fr

Gareth Howells

University of Kent
line 3: City, Country
e-mail address if desired

Matthew Pepper

Department of Medical Physics
East Kent Hospitals University NHS Foundation Trust
Canterbury CT1 3NG England
matthew.pepper@ekht.nhs.uk

Cecile Donzé

Groupe Hospitalier Institut Catholique de Lille
Rue Grand But, BP 249, 59462 Lomme Cedex, France
e-mail address if desired

Thierry Floquet

LAGIS – SyNeR Team
Ecole Centrale de Lille, Cité Scientifique, BP 48 BP 48
59651 Villeneuve d'Ascq Cedex, France
thierry.floquet@ec-lille.fr

Huosheng Hu

University of Essex
Colchester CO4 3SQ, United Kingdom
hhu@essex.ac.uk

Mohamed Sakel

East Kent Neurorehabilitation Unit
Canterbury, Kent, UK
e-mail address if desired

Abstract—This paper explains the motivations and the goals of the SYSIASS project. This project has three major ambitions: to design intelligent devices for both the assisted navigation of the powered wheelchairs and the secure communication of the data and to design multi-modality human machine interaction. Moreover, the challenge of the project is to take the needs of the users and the constraints that it implies into account at each stage of the project development. The devices developed during the project will be evaluated by the users through the clinical trials.

Keywords: assisted navigation for powered wheelchair, disabled people, secured data communication, multi-modality human machine interaction

I. INTRODUCTION

For most of us, mobility is essential to participate in life roles, the ultimate purpose of neurorehabilitation as defined by PRM by the Union Européenne des Médecins Spécialistes (UEMS) Section of PRM, WHO & UK incorporating International Classification of of functioning (ICF) which is an attempt to harmonise the conceptual model of rehabilitation across EU and the rest of the World [1]-[3].

The prevalence of wheelchair users is increasing in Western countries, estimated in the last decade at 60-200 per 10,000. The number of such users is expected to increase with increased survival from neurological conditions eg 80% of people with spinal cord injury are expected to depend on a wheelchair for the rest of their lives [4], [5].

National surveys in UK showed that Multiple Sclerosis and stroke survivors consider mobility as their top priority. Recent literature systematically reviewed the current pattern of usage of wheelchairs and measurement tools to test effectiveness of use [6], [7].

The flexibility to move without requiring human assistance may be beneficial to patient care, independence, quality of life and (re)integration into society. Arguably, access to data regarding the patient and the wheelchairs to the service providers, irrespective of the location of the patient, may provide an element of efficiency... Across Europe, with a progressively ageing population, policies for supporting older people are increasingly based on the premise that care should be provided efficiently to the patient wherever they are based

Hence, we need to think more broadly than in the past about the nature of the challenges which such a process will present and, in particular, it is becoming apparent that the two areas of (a) the nature of the care of disabled as well as older people and (b) the security of personal data will need to become more closely integrated if successful care programmes are to be established and effectively delivered.

The SYSIASS project aims to address a range of technological barriers currently inhibiting the uptake of new technological advances within the healthcare professions in the region with a special emphasis on technology related to the provision of effective and safe powered mobility [efficient administration of medical services at the point of delivery], and

in providing efficient secure communications to such points of delivery. An exemplar of such systems might be a system for the automated powered chair mobility and remote healthcare at a location convenient to the patient. This requires the integration of diverse capabilities in a robust and efficient manner. However, there are significant technical barriers which inhibit the employment of such technology associated with the construction of autonomous devices capable of aiding patient movement and ensuring that confidential data is communicated to such devices without the risk of interception.

As has been introduced, independent mobility is vital to maintaining quality of life for the non-ambulant person. However with physical and cognitive impairment there will also be impairment in the ability of the user to drive a powered wheelchair effectively and safely. It has been found that effective collision avoidance is a major requirement, to be able to drive in crowded areas, down narrow corridors and through doorways without collision. If the user or their carers feel unable to do this safely then the powered chair may be abandoned.

One reason for requiring this flexibility in performance is that some users will recover from a state of almost no physical function to independent control [e.g. Guillain Barre Syndrome], some will exhibit little or no change over time [e.g. Cerebral Palsy] and some will have a progressive condition where they begin with independent control of the chair and after a short period of time have little or no independent control [e.g. Motor Neurone Disease]. Additionally for each user group there will be a range of cognitive impairment. For example the user may have learning disability, a cerebral vascular accident with impaired spatial awareness or a neurological condition where cognitive ability deteriorates over time. People with visual impairments: a common residual deficit eg 1 in 2 stroke survivors will have these impairments and often without being aware of the impairments [8]. A Wheelchair Collision Test (WCT) has been proposed to be simple, reliable and valid test for screening such behavioural disability in powered chair users [8].

These challenges are further increased once the environment of use and safety [9] are added to the system specifications. The powered chair control system must be appropriate for typical user environments such as the home, hospital or school, where the location of furniture and familial objects as well as people will change over time.

The benefits that an intelligent powered wheelchair can offer the user and their careers are significant; the challenges to providing an appropriate control system are considerable. This paper will now outline how it is proposed to meet these challenges.

II. INTELLIGENT DEVICE FOR ASSISTED NAVIGATION

A. Context

To increase the autonomy of the disabled people, it is important to propose them an intelligent device for assisted navigation. Such device could help the person to move safely with its powered wheelchair. However, from the authors' point

of view, it is very important to take the user's needs into account, as well as their physical and cognitive impairment, and to offer them a personalized device which answers at their needs. Therefore one goal of the SYSIASS powered chair control system is to provide the user with the range of control options from being in full control of the chair using the standard powered chair joystick to autonomous navigation between chosen locations. Ultimately the system should be configurable to meet the changing needs of any user and should, therefore, be an "any user-anywhere" system. Therefore the control options will range from the user having full control without any "intelligent" intervention such as collision avoidance, to the user being navigated over a preset route without any user input apart from route selection.

For the autonomous navigation, the powered wheelchair must be able to locate itself in the environment, to detect the static and dynamic obstacles, to plan a safe trajectory and follow it. The SYSIASS project must provide low cost innovative solutions for these requires, taking all the constraints induced by the use of the manufactured powered wheelchairs into account. A software architecture for the autonomous navigation has been introduced in [10].

B. Main results

The kinematic model of the powered wheelchair is described by equation (1):

$$\begin{cases} \dot{x} = u \cos \theta \\ \dot{y} = u \sin \theta \\ \dot{\theta} = \omega \end{cases} \quad (1)$$

where $(x, y)^T$ is the position of the powered wheelchair, θ is its orientation and u and ω is its linear and angular velocities respectively. This model is the same that the model of a unicycle type robot. Therefore, it is possible to use the same algorithms as those developed for the unicycle mobile robots.

For the localization purpose, an algorithm using only a landmark and a monocular camera has been proposed in [11]. The landmark is detected by the camera, which measures its azimuth and elevation. By using these angle information and the kinematic model of the powered wheelchair, it is possible to estimate the powered wheelchair position $(x, y)^T$, as well as its linear and angular velocities. The wheelchair orientation could be measured by using a compass.

The distance between the wheelchair and the obstacles is measured by using IR and US sensors.

The path planning algorithm uses information provided by the localization and perception algorithms in order to calculate, at each update time, an admissible and free of collision trajectory for the wheelchair. In [12], [13], a path planning algorithm is presented for a mobile unicycle robot. The algorithm calculates in real time an optimal trajectory taking the physical constraints (velocity and acceleration limitations) and the kinematic model of the robot into account. In order to ensure that the wheelchair follows this free of collision trajectory despite of the perturbations, it is necessary to implement a tracking algorithm. An efficient sliding mode

control is proposed in [14], [15], [16]. The important thing is that the proposed tracking algorithm is practically sensible as no new measurements are required from the hardware and disturbances, as present in the real world, are accommodated. The impact of sensor failure is also considered. This is important as the patient must remain safe and it is desirable for the chair to operate in the presence of sensor loss.

C. Experiments

The first version of the intelligent device for assisted navigation has been implemented in an electrical wheelchair manufactured by a French company, DupontMedical (see Figure 1). It meets the requested scenario, defined by the medical staff from Hospital of Garches (France)



Figure 1: first prototype of the intelligent device for assisted navigation

The intelligent device detects obstacles, slows down the powered wheelchair proportionally to the distance between the obstacle and the wheelchair and stops it if the distance between it and the obstacles is less than the security distance, overriding any action by the user. It provides the user with visual feedback on the distance (measured by the sensors) between the wheelchair and the obstacles in its way. The user drives the powered wheelchair via a joystick and is free to use or not the intelligent device. This prototype will be evaluated by 27 users at Hospital of Garches (France).

III. DEVICE FOR SECURED COMMUNICATION

To ensure maximal effectiveness of the autonomous wheelchair technology being developed, it is advantageous that a secure and efficient means of wireless communication be available between the wheelchairs and other locations such as a central medical database. Such advantages include potentially introducing a high level control for the system, restricting the use of such technology to given times and locations and allowing timely personal medical data to be made available using the wireless medium. To achieve these aims, an efficient means of encrypting any transmitted data is required to prevent the potential compromise of personal medical data and ensure the data is only available in authorized locations.

The SYSIASS project is addressing this issue by developing a technology based on the direct generation of encryption keys based on measurable properties of electronic devices such as the wheelchair termed ICmetrics. The need to protect the integrity of each wheelchair has long been recognised, but the increasingly widespread adoption of embedded devices raises new challenges, particularly where these devices are communicating autonomously. ICmetrics represents an exciting new approach for generating unique identifiers for embedded devices enabling secure encrypted communication between devices potentially significantly reducing both fraudulent activity such as eavesdropping and device cloning.

While data encryption techniques are now highly sophisticated and well established, encryption itself cannot necessarily protect against fraudulent data manipulation when the security of encryption keys cannot be absolutely guaranteed. The use of ICMetric authentication represents a novel concept of regulating access to devices and is explicitly aimed at providing protection at the especially vulnerable points where data access is initiated.

Specifically, ICmetrics possess the following significant potential:-

- Secure communication to and from each wheelchair devices via the direct generation of digital signatures and encryption keys from the internal behavioural characteristics of software and hardware associated with the wheelchair. This naturally implies the major advantage that no encryption keys or device characteristic templates are stored.
- Prevention of unauthorised access to the systems and devices associated with the wheelchair which are increasingly connected wirelessly.
- Prevention of the fraudulent cloning or imitation of the electronics associated with the wheelchair in order to compromise its identity and subsequent communication which could compromise sensitive medical data.
- Implicit detection of tampering of the software or hardware associated with the wheelchair via the inclusion of spyware or similar virus software since this will implicitly cause the ICmetric generated digital signature to vary.

A significant novelty of the proposed ICmetric technology lies in the potential for the *direct encryption* of data extracted from ICmetric samples which characterise the identity of the wheelchair. Such a system offers the following significant advantages:-

- The removal of the need to store any form of template or reference data for validating the wheelchair, hence directly addressing the potential major weakness that the feature templates may be accessed and used to circumvent the security afforded by the system.
- The security of the system is as strong as the ICmetric and encryption algorithm employed (there is no back door). The only mechanisms to gain subsequent communication access with the wheelchair are to provide another sample of the ICmetric or to break the cipher employed by the encryption technology.
- The compromise of a system does not release sensitive ICmetric template data associated with the wheelchair which would allow unauthorised access to other systems protected by the same ICmetric such as an associated medical database or indeed any system protected by any other ICmetric templates present.
- Tampering with the constitution of a circuit associated with the wheelchair will cause its behaviour to change, potentially causing the features underlying the ICmetric to change, perhaps dramatically, thus causing the generated ICmetric to change. Consequently, a faulty or maliciously tampered device will be autonomously prevented from decrypting its own stored data or participating in any initiated secure communications, as the regenerated keys will differ from those created before its integrity was compromised. i.e. the ICmetrics approach can be made to fail securely and provide a very high immunity from cloning and tampering.
- The removal of the need for the storage of the private key associated with the encryption system. This is a natural consequence of the system since the key will be uniquely associated with the given ICmetric sample and a further ICmetric sample may be used to regenerate the required private key. As there is no physical record of the key, it is not possible to compromise the security of sensitive data via unauthorised access to the key.

Details of the operation of ICmetric system may be found in [17], [18] and a more detailed overview of its exploitation in a medical environment may be found in [19]. The basic operation of the proposed ICmetric system is as follows. The system is a two phase operation employing a number of known wheelchair circuits as a calibration set with each phase as follows:-

Calibration phase (applied once only per application scenario)

- 1) For each sample wheelchair circuit: record a set of desired measurements associated with the circuit known generically as features.

- 2) Generate feature distributions for each feature tabulating the frequency of each occurrence of each discrete value within the given value scale for each sample circuit.
- 3) Normalise the feature distributions generating normalisation maps for each feature.

Operation phase (applied each time an encryption key is desired for a given circuit)

- 1) Measure features for the given wheelchair circuit for which an encryption key is desired.
- 2) Apply the normalisation maps produced during the calibration phase in order to generate values suitable for key generation.
- 3) Apply the key generation algorithm.

At the conclusion of the normalization phase, the feature values are combined to form a number that uniquely identifies each circuit the details of whose operation may be found in [18].

The initial performance measurements using features associated with potential wheelchair circuits is encouraging although, as the wheelchair is still under development, experiments on the completed system are awaited in order to verify these results. It is also anticipated that the system will also be suitable for employment with unseen wheelchair circuits which have not been employed during the calibration phase of the system. This would represent a significant advantage as it would allow for the immediate integration of a new wheelchair which the secure communication system without the prior need to enroll the device.

IV. HUMAN-MACHINE INTERFACE FOR HANDS-FREE CONTROL

A. Context

Recently, multi-modality human machine interaction (MMHMI) is emerging as a new concept for developing human machine interfaces (HMIs) as it supplies a natural and comprehensive way of communication. These features are especially helpful for people who have severe disability and have very limited capability in controlling assisted tools such as intelligent wheelchairs and robotic artificial limbs [20],[21].

Compared with single modality HMIs such as a traditional joystick controller, single EMG controller or other single modality human motion tracking based control methods, multi-modality HMI can benefit from the 3 aspects:

- 1) *Expanded usability and controllability - Integration of multiple modalities into HMIs would potentially enrich the controllability of the interface;*
- 2) *Refined adaptability and flexibility – to optimize the combination from a number of potential communication methods, and customize itself into a special communication method for each user;*
- 3) *Higher accuracy and better robustness –fusing various complementary information into a MMHMI will improve the overall performance of the interface.*

However, in order to design a MMHMI, its components need to be fine-tuned for better performance. There are some

factors need to be considered such as human movement patterns or biometric features. Also, the trade-off among efficiency, accuracy, flexibility and robustness needs to be decided carefully. Efficiently interacting with such HMIs will benefit those who have limited moving and acting abilities.

B. Experiments

As shown in Fig. 2, two modalities, i.e. EMG signal from user forehead and face image information from camera fixed in front of the wheelchair, are synthesized to analyze human facial movement features. Subsequently, two types of data, i.e. image pixel data and EMG waveforms will be processed according to their own features. As the movement features in both modalities are steady and distinctive, we apply pattern recognition algorithms separately to each modality for feature and pattern classification purpose, and thereafter the classification results from both modalities are combined according to a combination of logic rules depicted in [22]. This procedure is depicted as a feature fusion of the two types of modalities' data.

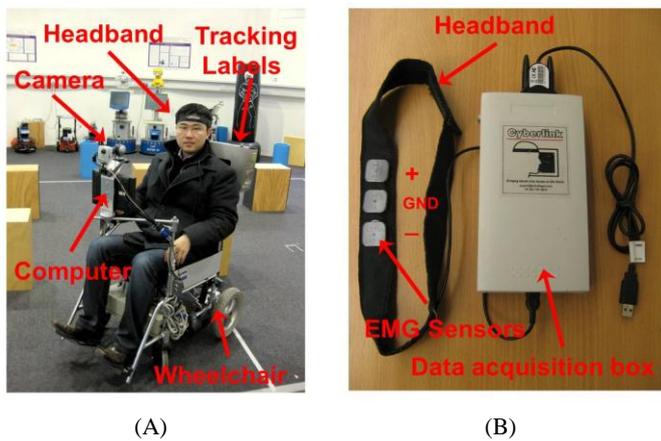


Fig. 2 (A) A subject sitting in wheelchair and wearing Cyberlink Brainfingers™ headband; (B) The Cyberlink Brainfingers™ data acquisition box and the headband.

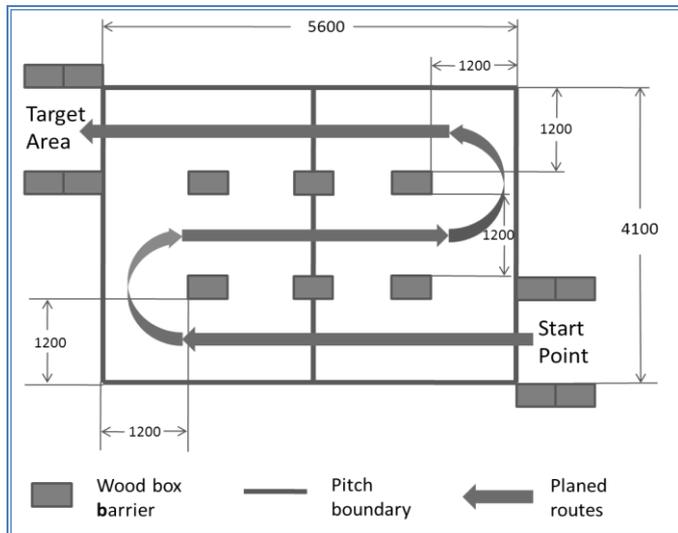


Fig.3 Diagram showing the dimensions of the experiment layout and the planned routes in the task

As shown in Fig. 3, an experiment site is designed and consists of a combination of doorways, corridors, turning corners and docking places. In order to control the wheelchair going from the start point to the target area, the subject have to control the wheelchair to go through three corridors and make two major turnings with one left turning and one right turning each, and finally passes through a doorway to the target area for docking.

C. Main Results

Fig. 4 shows ten trajectories that were recorded when a subject controlling an intelligent wheelchair with EMG and vision based control method and following a planned route from start point to target area for 10 times. It is clear that the proposed two modalities, visual and EMG data, can be effectively deployed in a MMHMI by a subject to control the wheelchair smoothly.

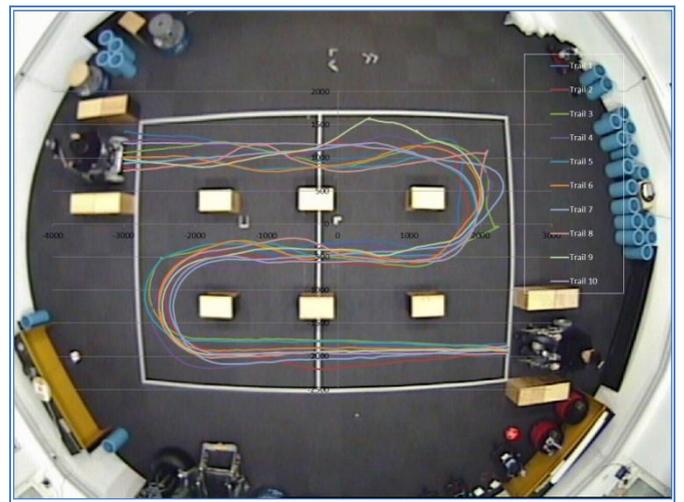


Fig. 4 Ten successive trajectories

V. CONCLUSIONS

The goals and challenges of the SYSIASS project have been presented. The ambition of the project is to offer to disabled people personalized solutions in term of assisted navigation, secured communication of data and human-machine interfaces, which answer at their needs and which take their physical and cognitive impairment into account. These solution must be low cost and don't ask major transformations on the user's environment.

For the assisted navigation, the challenge is the development of new localisation algorithms, using low cost both sensors, like monocular camera, and landmarks. The safe navigation is also required. For this, new path planning and tracking algorithms will be designed. The first prototype of the assisted navigation device is being tested by the users at the Hospital of Garches (France).

For the secured data communication, the ICMetric technology is proposed. It represents a novel concept of regulating access to devices and is explicitly aimed at

providing protection at the especially vulnerable points where data access is initiated. A significant novelty of the proposed ICmetric technology lies in the potential for the *direct encryption* of data extracted from ICmetric samples which characterise the identity of the wheelchair.

A multi-modality human-machine interaction using the EMG signal from user forehead and face image information from camera fixed in front of the wheelchair are used to control the powered wheelchair smoothly. The first tests realized by a healthy person proof that the MMHMI could be more efficient to maneuver the wheelchair than the use of the joystick.

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