Research Results of the Department of Control Engineering and Information Technology in 2015

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Abstract
This report reviews the research results obtained in 2015 at the Department of Control Engineering and Information Technology.

1 Introduction

Research activities at the Department of Control Engineering and Informatics (IIT) are regrouped into five well-defined focus areas. Results achieved in 2015 are presented in the subsequent sections following a similar breakdown. Section 2 is devoted to digital systems. Results in the field of parallel processing and software technology are presented in Section 3. Section 4 describes achievements in visual informatics, including topics related to medical image reconstruction and augmented reality. Finally, Section 5 is devoted to robotics, process control and identification. Although subsections provide in-depth information and references, it is convenient to highlight some of the key results at the beginning of each section.

2 Digital Systems

A front-end high level synthesis tool is under development capable to determine the optimal multiprocessing architectures for given tasks, specified in the C programming language. Our active fish tagging system offers a cheap and reliable way to accurately follow the behaviour of a fish population in swallow fresh water environment of limited range.

2.1 System level synthesis

Multiprocessing can be considered as the most characteristic shared property of complex digital systems. Due to increasingly complex tasks to be solved for fulfilling often conflicting requirements, the system architecture is strongly determined by the task to be solved. The consequence of this task-dependency is that the component processors of such systems are usually not only general purpose CPUs or cores, but also DSPs, GPUs, FPGA-s and other custom hardware elements as well.

The rapid development in multiprocessing demands new system-level synthesis methods supporting the designer in finding the proper heterogeneous multiprocessing architectures (HMPA). The aim is to develop an experimental HMPA system level synthesis tool (called DECHLS) relying on the decomposition and high level synthesis algorithms. DECHLS receives the task to be solved as a C code and after performing the task decomposition assigns the subtasks into component processors considering the requirements and their priority order definable by the designer. The application of the DECHLS has been illustrated and evaluated on practical examples [1][2][3][4].

2.2 Active fish tagging an tracking system

Tagging and tracking fish is important in fish-pond farms. Fish tracking is used to study the behaviour of the animals. An active tagging system has been developed, which consists of active tags placed on several fish, and also a number of stationary transceivers or base stations. Since the tags operate on battery power, their transmissions should be short. The base stations also have solar power, therefore they can transmit for longer periods and also they can be equipped by a higher power transmitter. The position of an active tag is estimated based on RSSI (Received Signal Strength Indicator) values. The tag communicates only with the nearest base station. Data visualization may be performed on a remote server [11].

3 Parallel Processing and Software Technology

Parallel versions of analysis tools for properties of truss systems were implemented to verify and improve existing conjectures. A user friendly service description language (SOAL) is designed for distributed applications from heterogeneous software components.

3.1 A parameter based approach to the analysis of quadrilateral grid trusses

Certain mechanical properties of two-dimensional truss structures can be observed using discrete mathematical means. Fast algorithms allow efficient analysis of a single structure of higher complexity. We studied the possibility to process a very large number of structures via a distributed execution of such algorithms, taking advantage of high-performance computing infrastructures [20].

The identity of the smallest quadrangulation with minimum degree 3 also containing parallel edges is unknown. However, it has already been determined that its order (the number of vertices) is between 11 and 14. We have narrowed this domain by showing that the order is at least twelve [21].

3.2 Distributed service description language

Service-Oriented Architecture (SOA) defines a set of principles for connecting distributed software components. Although SOA is primarily implemented by web services, other technologies (REST, WebSockets, CORBA, etc.) are also suitable for implementation. The main challenge in creating a distributed system of services is the lack of user friendly description of the overall system and of the individual service interfaces. Microservices is a new emerging concept for creating distributed applications from heterogeneous software components. As microservices also lack a general description language for defining the components of the application a user friendly distributed service description language has been developed, called SOAL. The language is suitable for defining the architecture of large scale SOA systems and small scale microservice applications [22].

3.3 Automated test data generation with JPA

The availability of appropriate test data is critical in order to develop complex software efficiently. Generally, test data is assembled with time-consuming manual steps, which becomes more and more cumbersome as the system evolves. A new object oriented approach, based on the Java Persistence API has been suggested which may evolve incrementally with the software being developed. In this way the whole development and testing process gets a more natural continuity [23].

3.4 Software quality assessment

We investigated the possibilities to use product-based and process-based software quality approaches in an integrated way. A successful new direction in combining software quality-oriented knowledge and methods was the development of a new methodology based on text analyses and data mining via performing similarity analyses between international quality approaches [24][25][26].

4 Visual informatics

The results of the Computer Graphics group cover topics including computer aided geometry design, augmented reality (AR), tomography reconstruction and visualization.

4.1 Computer aided geometric design

In the field of digital shape reconstruction of CAD models based on measured point clouds, new results emerged in detecting and enforcing various engineering constraints (i.e. parallelism, orthogonality, tangency, best fit coordinate system, symmetry, etc.) [8]. Designing complex shapes requires interpolating free-form curve networks in 3D. We developed various, new multi-sided transfinite surfacing schemes within a loose cooperation with the Boeing Company and KAUST (Saudi Arabia). Global parameterization (flattening) of complex 3D triangular meshes is an ill-posed problem. New parameterization techniques have been developed to align mesh curves and regions with prescribed geometric entities [11]. We also studied an important area of combinatorial geometry. Our focus was directed to investigate hard problems to decompose multiple coverings by shapes in the plane [9][10].

4.2 3D shape recognition for adaptive tangible AR

A particular type of AR systems, called Tangible Augmented Reality (TAR) combines the idea of Tangible User Interfaces (TUIs) with Augmented Reality, creating an environment in which users touch real-world objects, while interacting with virtual ones. This allows for intuitive, natural user interfaces, while removing a conflict between different senses. In most cases, however, TAR systems require the preparation of the physical environment in order to function (markers, or special real-world objects). Our goal is to create a system that is able to process a previously unknown environment and find real-world objects that are fitting placeholders for the virtual objects. In our system, the shape of an object or a scene is represented as a graph of primitive shapes (planes, spheres, etc.). The key algorithm is a learning classification that uses 3D shape data to pair virtual and real objects. In our current research, we use node-by-node graph matching to improve accuracy, and to allow for easy alignment of the virtual objects. For this purpose, we proposed a discriminant analysis method that handles between class discrimination and the separation of nodes within a single graph at the same time [5][6].

4.3 3D reconstruction and AR using depth cameras

Current depth cameras are able to add geometry information to colour images. To exploit this information, real-time, 3D object reconstruction methods are needed, and the resulting 3D scene can augmented with virtual objects and can be viewed from arbitrary viewpoints. We have developed GPU based algorithms that fused the information of multiple frames, filtered the noisy depth values based on the information of the colour cameras and addressed the occlusion problem [12]. The models obtained in this way can augment virtual scenes or can be rendered with special techniques, e.g. with non-photorealistic rendering [15].

4.4 Emission tomography reconstruction

Positron Emission Tomography (PET or SPECT) aims at the reconstruction of the 3D density of radiotracer materials from the observation of simultaneous gamma-photon detector hits, originating at positron-electron annihilations. The reconstruction process requires the accurate simulation of the complex physical phenomena and an optimization method searching for the maximum-likelihood estimation. Due to the limited allowable radioactive dose, reconstructions are typically of low resolution and noisy. We addressed the problem of dynamic reconstruction, when the time functions of the activity are reconstructed [16]. We have developed an GPU-based enhancement process that can reduce noise while increase the sharpness of the true signal and significantly increase the resolution using information provided by other, e.g. CT or MRI modalities [13] [37].

We have adapted the Algebraic Reconstruction Technique (ART) to the optimal BCC lattice and compared it to its traditional implementation on the CC lattice [19]. On the CC lattice we used a trilinear interpolation kernel, while on the BCC lattice we tested a four-directional box- spline kernel and a trilinear B-spline kernel. The BCC lattice combined with a trilinear B-spline kernel resulted in the most isotropic volume representation.

4.5 Shape-based Interpolation

We have shown that a shape-based interpolation of 2D and 3D density distributions can be implemented by a distributional interpolation of the Radon transforms. Recently, we have proven that a 3D shape-based interpolation based on this approach is completely consistent as the interpolated 2D projections are the 2D projections of a valid 3D density distribution [17].

4.6 Comparison of CC, BCC, and FCC lattices in terms of prealiasing

Previously, Cartesian Cubic (CC), Body-Centered Cubic (BCC), and Face-Centered Cubic (FCC) lattices have been compared in terms of prealiasing by sampling and reconstructing the well-known Marschner-Lobb (ML) test signal. We have shown that such a comparison gives an unfair advantage to the FCC sampling due to the anisotropic spectrum of the ML signal and the axis-aligned orientation of the sampling lattices. For the sake of a fair comparison, we proposed to rotate the lattices such that the prealiasing effect is maximized on each lattice [18].

5 Control engineering and robotics

New methods were developed to manage singular configurations in robot invers kinematics, to model tumor behaviour and control the therapy. A new sensor fusion technique is proposed for under-actuated mechanical systems using unscented Kalman filters.

5.1 Developments on the differential solution of the inverse kinematics problem of robot arms

The problem of finding the joint trajectories for the desired end effector motion for robotic arms is called the inverse kinematics problem. Its solution involves a system of nonlinear equations. An applicable method to solve the inverse kinematics problem is based on the linear approximation of robot motion which may become singular. An earlier regularization technique was developed further for the inverse positioning problem of generic robot arms and for elbow manipulators in particular [27]. The numerical integration that has to be done after the solution of the linear system was improved by applying the Crank-Nicolson (CN) method so that the convergence of the linearized solution to the real solution is faster compared to the Euler method [28].

5.2 Modelling and control of physiological processes

Our research interests covered a wider range of processes relevant to the behaviour and treatment of the human body, including retina function identification [14], breath cycles [33], and glucose absorption [34].

Developments in antiangiogenic tumor therapy were carried out in cooperation with the Physiological Controls Group from the Óbuda University. A new method was proposed to approximate the tumor volume based on caliper measurement [29][30]. Application of state-feedback on the linearized Hahnfeldt tumor growth model was analysed, along with the effect of the choice of the operation point used in the linearization. The range of design parameters that result in stable closed-loop was given [31][32].

5.3 State estimation of under-actuated mechanical systems using Kalman filters

Under-actuated mechanical systems (e.g. cranes) exhibit oscillatory behaviour. Powerful non-linear feedback techniques require full state information but not all state variables are usually measured, hence some state estimation technique must be applied. The sampling time of the sensors may be different and some sensors may provide measurement information asynchronously. An unscented Kalman filter based sensor fusion method has been developed and successfully tested on a reduced sizes mechanical testbed system [38][39].

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