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## Table of Contents

### Preface .................................................................................................................................................. iii

*Innovation strategies for research technologists engaged in sports and health applications*
Daniel A. James........................................................................................................................................... 1

*Research in the Triangle of the School of Engineering, the School of Medical Sciences, and the Gold Coast Hospitals*
Andreas Öchsner ......................................................................................................................................... 3

*On the preliminary design of an instrumented ball for sports applications*
Hugo G. Espinosa, Andreas Øchsner, Ali Mirnajafizadeh, and Daniel A. James ................................. 5

*Non-destructive detection of defects in composites - technology and applications*
Huaizhong Li, Wayne Hall, and Andreas Øchsner .................................................................................. 7

*Platform Technologies and Visualisation Tools for Sensors in Sport and Health Applications*
Raymond Leadbetter, and Daniel A. James ............................................................................................... 9

*Optimising for power in wearables*
David Rowlands, Mitchell McCarthy, and Daniel James ......................................................................... 11

*Microwave Imaging for Biomedical Applications*
Andrew Seagar ......................................................................................................................................... 13

*Novel Robust Sensor for Intraoral Bite Force Measurement in Human Subjects*
Jarred Fastier-Wooller, Hoang-Phuong Phan, Toan Dinh, Tuan-Khoa Nguyen, and Dzung Viet Dao ................................................................................................................................. 17

*Assessing the impact of integrating IMU wearable technology in an elite netball training environment for performance analysis*
Jonathan Shepherd, Christine Voge, David Rowlands, and Daniel James ........................................... 19

*Designers Don’t Text - They Visualise: Integrating Coding into the University Design Curriculum*
James Novak, and Jennifer Loy .................................................................................................................. 21

*Modelling resistance exercise lifting technique with inertial sensors: Knee extension during deadlifts*
Sam Gleadhill, Daniel James, and James Lee ............................................................................................ 23

*Progress in Metal Additive Manufacturing towards a Wide Implementation in Dentistry*
Leonhard Hitzler, Frank Alifui-Segbaya, Wayne Hall, and Andreas Öchsner ...................................... 27

*Using Inverse Finite Element Simulation to Characterise Soft Tissues by MSC Marc/Mentat*
Zia Javanbakht, and Andreas Öchsner ..................................................................................................... 31

*Fused deposition modeling of 3D parts using acrylonitrile butadiene styrene (ABS) polymer*
Maksym Rybachuk, Charlène Alice Mauger, Thomas Fiedler, and Andreas Öchsner .......................... 33
Preface

Welcome to this special edition focused on Human Technologies. For the last decade our university has been engaged in biomedical and sports engineering research activities. The former had been something of a curiosity and the latter the source of some amusement until this new field began to transform the way sport is played.

Today our engineering school encompasses a wide variety of disciplines that contribute to biomedical and sports engineering research activities. We recognise these as Human Technologies as there are many similarities between the two application areas. Engaging in human technologies requires a mind-set shift for the research tyro and experienced alike requiring often that it become a holistic human centric activity, rather than something to be done in the lab that we might try and fit to a human benefit.

This special edition is a snap shot of recent and emerging research activities, and encompasses strategies to engage with industry, the medical community featuring work on sensor and devices, modelling/simulation and experimenting. It features activities from SABEL Labs, gCORE, School of Engineering, School of Medical Sciences and some of the hospitals in the vicinity of our campuses. We hope you enjoy reading this as much as we did writing it.

December 2016

Daniel James and Andreas Öchsner
Innovation strategies for research technologists engaged in sports and health applications

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Keywords: Innovation, Platform Technologies, Strategy.

Extended Abstract. The challenges of bringing research from out of the laboratory to have impact in the application areas of sports and health are many. The least of which is that bench based experiments are not nearly so predictable as working with humans. In this case its useful to take a step back from our daily activities, that of pursuing our very interesting lines of enquiry to ask ourselves some rhetorical questions. How do we reach out? and are there processes that can be helpful for this? Happily there are and innovation is more than just a buzzword, there is actually considerable body of work behind this. It is said that innovation is creativity plus implementation. Creativity is something we do very well in the research context, implementation is where specific demand-pull from industry can be very helpful in providing direction.

Some very useful approaches come from the innovation and particularly the startup literature [1], where run lean and moving with agility are important. Also its helpful to think about who our customers might be. Of course using the language of ‘customers’ is somewhat strange to use in a research context, where granting bodies and journals might be our only contact with the world. Getting our name out there might involve some thought for marketing, which includes talking to people and generating good word of mouth [2] and in the world of sports, some thought to branding is also important [3]. Its also useful in some senses to think of our partnerships with other researchers, sports organisations and private industry as business to business (B2B) customers. The next step is building a kind of intimacy with them, which is important to understanding their needs and the demand pull, it's a fairly common strategy these days [3]. In our laboratory, where our specialty is wearable sensors [4] we realized that setting up the building blocks for each project where often the same and there were great efficiency gains (operational efficiency) to be made here. By identifying this it made life easier for student researchers and reduced our response time to trying out an idea or meeting a partner’s needs. Thus we developed a series of platform technologies using our sensor expertise [5] around a hardware and software framework [6], built with the need for flexibility in mind and thus could be applied to a variety of application [7]. In fact the tool soon became quite popular within our networks and so was a way to rapidly gain scale through developing partnerships around the technologies, where our core domain expertise in wearables was helpful in working in a transdisciplinary way with specialist sports and health applications.

With the research environment constantly under challenge, the adoption of these approaches around a core area of expertise can help protect and expand areas of research strength. Together with judicious use of strategies used in technology industries [8] it can help meet the emerging agendas of research and innovation together with the requirements to work more closely with external organisations and businesses.
References


Research in the Triangle of the School of Engineering, the School of Medical Sciences, and the Gold Coast Hospitals

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Keywords: Griffith University, Health and Knowledge Precinct, Gold Coast University Hospital, Gold Coast Private Hospital, Gold Coast Commonwealth Games Village, Interdisciplinary Research.

Extended Abstract. Griffith University Gold Coast Campus is growing in the next few years in a unique infrastructure, the so-called Gold Coast Health and Knowledge Precinct, see Fig. 1. Residing after 2018 in the former Gold Coast Commonwealth Games Village, this project will assemble in the closed neighborhood the teaching and research facilities of Griffith University and two new and modern hospitals to strengthen and coordinate research, for example, in the biomedical area. It should be not forgotten that this precinct is situated very close to Surfers Paradise and the famous Gold Coast beaches, easy to access via the new Gold Coast Light Rail.

Figure 1. Stakeholders of the Gold Coast Health and Knowledge Precinct.

This unique infrastructure and a research focus in the biomedical and bioscience area opens new research opportunities for the School of Engineering, especially for the Disciplines of Mechanical, Electrical/Electronic as well as Mechatronic Engineering. The following list summarizes a few projects, which were already designed in this new context of multidisciplinary research:

- 3D printing of artificial bone scaffolds based on the polymer printing facilities in the School of Engineering [1,2], experimental testing and numerical simulation [3,4,5] under the consideration of damage evolution [6].
- Finite element characterization of biological materials with depth-sensing indentation [7].
• Numerical simulation and experimental investigations of trabecular bone [8,9]; in cooperation with University Technology Malaysia.
• Application of selective laser melting in dentistry [10]; in cooperation with the School of Dentistry and Oral Health (DOH).
• Fracture resistance of lithium disilicate crowns in simulated oral environment [11]; in cooperation with DOH.
• Systematic pilot study on radial head fracture; in cooperation with Gold Coast University Hospital (GCUH).
• Design of a monitoring system for club foot correction; in cooperation with GCUH.
• Bite strength in human facial morphology [12]; in cooperation with DOH and Griffith Criminology Institute.

References
On the preliminary design of an instrumented ball for sports applications

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Keywords: cricket, inertial sensors, bowling, bat, smart ball, impact forces, shock absorption.

Extended Abstract. An instrumented hard ball that can measure aspects of athlete’s/player’s performance including flight time, rotational velocity (spin), distance, velocity and impact forces, is being developed. The Smart Ball will allow coaches to work with quantifiable outcomes from the flight of delivery for each bowler. In the case of a spin bowler, different strategies for a bowler’s action can be assessed in terms of how many revolutions per second, and therefore ability to spin the ball, have been imparted onto the ball as it leaves the bowler’s hand. The technology transmits a wireless signal and/or stores the characteristics of the ball’s flight. The characteristics of the ball are not altered. The instrumented ball uses a series of mini inertial sensors, such as tri-axial accelerometers, gyroscopes and magnetometers that are encased in a novel impact resistant housing.

An in-house sensor platform based on SABEL Sense [1, 2] is being used on the instrumented ball. The platform consists of wearable sensors that collect data from digital MEMS (Microelectromechanical systems) inertial sensors. The accelerometer is capable of measuring acceleration forces of ±10g in three perpendicular directions (g being the gravitational force). The platform contains wireless connectivity (2.4 GHz) for real-time data streaming.

The sensors allow for the determination of quantifiable measures of ball flight, impact and usage. An impact proof system, together with a shock damping structure are required for the protection of the electronics. The average force acting on the ball during the hit is approximately 10 kN for a velocity of 25 m/s [3]. The challenge lies in the development of a shock protection system, which is being developed through the assessment of different materials such as foams, cork, polycarbonates, nylon, and novel structures based on the trabecular bone structure of the body to protect the electronics from very large shocks, yet maintain the structural integrity and feel of the ball to players. These materials are being tested using a drop test tower.

The dynamic impact characteristics will be determined experimentally through the coefficient of restitution [4, 5] and contact time. In addition, a Finite Element model will be used to determine the contact properties associated with impact between cricket balls and bats [6].

The final prototype will result in a technology with the potential for large impact on sporting performance coaching. Due to its portability, the ball kinematics will be determined in an outdoor environment.
References


Non-destructive detection of defects in composites - technology and applications

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Keywords: Composite structures; Defects; Non-destructive detection; Vibration.

Extended Abstract. Advanced composite materials such as fiber reinforced plastics offer distinct properties including high strength and low weight, good vibrational damping, low coefficient of thermal expansion, fatigue strength, resistance to corrosion, oxidation and wear. They are now widely used in aircraft, aerospace, automobile, marine, and sports equipment sectors. However, defects in composite structures can occur during materials processing, component manufacture, or in-service use, which make the composite structures susceptible to reduction in performance [1]. Many defect types may exist in composite structures, for example, cracks, delamination and debond, impact damage, embedded foreign objects or contamination, voids [2]. Among these, delamination and debond are considered as the most commonly observed failure modes in composite structures [1]. The presence of defects can affect the strength of composites, reduce the buckling load capacity and the stiffness substantially, which in turn will affect the structural performance and cause failure of composites [3]. It is important to be able to discover the defects in an early stage to avoid potential catastrophic consequence. Since damage is often hidden within the structure, with little to no surface indication, non-destructive testing approaches must be evaluated and employed. There are numerous non-destructive testing (NDT) techniques that have been developed for the inspection and detection of defects in composite structures without damaging the component. Examples of available non-destructive defect detection methods are ultrasonic testing, radiography, interferometry, X-ray, thermography, microwave, eddy current and acoustic emission [2,4]. Different principles are employed in each of these techniques to detect the defects in the materials. Considering the diversity of the shape, size, physical and material properties of the component being tested, different NDT approaches may have different advantages and limitations.

Ultrasonic testing is a very efficient method for materials quality inspection. It uses high frequency sound signals beyond human hearing (> 20 kHz) to evaluate the depth and size of the nonconformity by analyzing the measured change of sound amplitude as the sound passes through the material. There are two basic ultrasonic detection approaches. The pulse-echo (A-scan) detection is by analyzing the reflected sound signal, while the through transmission (C-scan) method is by analyzing the transmitted signals through the material [2,5]. Ultrasonic inspection is very sensitive to commonly found defects in composites such as delamination and debond. However, it is a local detection approach, which may take significant amount of time due to the limited scanning rate. Radiography involves penetrating the object with short wavelength electromagnetic radiation [4]. Computed tomography (CT) is a new and precise radiography NDT method. It uses a scanning head that rotates around the object and an X-ray beam passes through the object and produces a set of slices, which are reconstructed to the three-dimensional data array [6]. The industrial CT can achieve a very high spatial resolution of lower than 1 \textmu m, which allows for identification of even single fibre breakage in the fibre-reinforced composite structure [6]. The main challenge for using the CT method is on the interpretation of measurement results caused by the measurement noise and artefacts. The very high cost of inspections is also a major concern [6]. In thermography testing, a composite structure is excited by an external heating source. The differences in a temperature distribution on its surface are observed through infrared (IR) imaging recorded by an IR camera to detect defects within the component [4,6]. The principle behind is that the existence of defects will disturb the heat flow and hence can be detected [4]. The aforementioned approaches can be classified as local-damage detection methods which are usually time consuming and costly.
For large and more complex structures, there is often a demand for quick detecting of damage throughout the whole structure, which requires global-damage detection methods. Global vibration-based structural damage detection has been proposed in [7,8]. It is believed that defects within the structure can cause a change in the structural dynamic properties in terms of the frequency response function (FRF) and modal parameters of the structural system. Therefore, detection of the change of the structural modal parameters including natural frequencies, modal damping, and modal shapes can be used as a signal of early damage occurrence within the composite component [9]. The current vibration-based method is model-dependent which means that the accuracy of the model affects the effectiveness of the method significantly. The current study aims to develop a hybrid method for rapid and reliable detection of defects in composite structures, which will use a vibration based approach for a rapid global detection to check if a defect exists, and then followed by a local detection method to find out the exact location and type of the defect. The developed method will be applied to detect the damages in composite sports equipment such as a hokey stick.

Figure 1. Experimental setup of vibration-based defect detection

References

Platform Technologies and Visualisation Tools for Sensors in Sport and Health Applications

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Keywords: Inertial sensors, MATLAB, Human monitoring, 9DOF, visualisation

Introduction: Inertial sensors have been a key component in human movement studies conducted in the lab [1]. An in-house inertial sensor system was created over several iterative development stages [2]. The in-house system provides the flexibility and customisation required by the lab.

A large variety of trials are performed in the lab, consisting of high intensity tasks such as cricket monitoring [3] and running gait; medium intensity activities such as swimming [2]; and low intensity daily tasks such as walking or lifting [4]. The sensor system hardware must be flexible enough to capture the wide range of expected intensity, while still maintaining a useful resolution for analysis. The software controlling the sensor system is required to be robust, user-friendly, and highly customizable. A key requirement of the software system is to provide easy to use video and inertial sensor synchronisation. This aids in data analysis by providing a reference to key events and patterns.

Results: The variety of activities requiring monitoring led to the development of sensor hardware with a dynamically adjustable measurement range. The primary inertial measurement unit (IMU) used by the sensor device (MPU-9150) has an adjustable accelerometer scale (2/4/8/16g) and an adjustable gyroscope scale (250/500/1000/2000deg/s). This measurement range meets most of the system usage cases. High intensity tasks required the development of a modular daughter board with sensors capable of measuring up to 200g and 6000deg/s. The desired measurement range is set in software to meet the user’s specific application.

Discussion: The software was developed to perform two primary purposes. First is sensor control, using a wireless link from a PC the user can interface to all sensor devices. The sensor interface provides device status (battery life, logging state, previous sessions) and device control, allowing for sensor configuration changes, data download, and network control. The second primary purpose is data analysis, which often starts with viewing synchronised video and sensor data. The synchronisation process was streamlined by using a synchronisation LED combined with wirelessly connected sensors. The synchronisation LED is filmed when a sync marker command is sent from the software, as shown in Figure 1. This provides a reference frame in the video and the system marks the location in sensor data. This allows for semi-automated synchronisation, as the user must only input the correct video frame.
Figure 1 Demonstration of a synchronisation command from the sensor system.

Once the data is synchronised the analysis tool [6] can be used to mark locations of key events and patterns. The software can also be used to apply certain data processing techniques, including filtering and sensor orientation estimations [5]. This assists the user in visualising the inertial sensor data and the effect of movements on the device.

Conclusion: The developed inertial sensor system has helped service the lab by providing a flexible measurement device to suit a wide range of applications. Future development will continue to refine the system based off user demands and technology advancements. Development is progressing into the cloud by integrating the system with a recently developed cloud-based data storage system. This provides a searchable database with data tagging and indexing, with the ability for data distribution and sharing between lab members.

References:


Optimising for power in wearables

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Keywords: Wearable, IMU, Inertial Sensors, Optimisation, Power

Introduction: Recently the popularity and application of wearable technologies has greatly increased in the medical, sporting and consumer space [1]. These wearables are typically used for activity classification and monitoring of sporting actions [1,2]. There are a number of features that are common to all Wearable technologies:

- They must be small and light weight so that they do not affect the activity being monitoring.
- They have a sensor or sensors to monitor an activity. Typically these are inertial sensors.
- They have sufficient storage to collect the data from the activity being.
- They have a communication system to transmit the data to a remote device such as USB, Bluetooth etc.
- They have a powerful enough microcontroller with appropriate firmware.
- They have a large enough battery to allow sufficient time between recharging.

The issue of the time between charging Wearable devices is significant since it can affect the duration of activity measurement and whether or not the processing is performed on the device or off the device. Processing off the device will limit the ability for Real Time Monitoring but processing on the device will limit the battery lifetime. This means that the hardware and the software will both affect the time between battery recharging since both affect the power drain of the battery. This paper will discuss what can be done to optimise both the hardware and the software to reduce the power usage. Since a typical use of Wearable technology requires the use of classifiers, then a case study showing the effects of the varied classifiers is also presented.

Hardware and Software: There are a number of procedures that can be performed to reduce the hardware power drain:

- Reduce the active time of the processor [3]. This means that it is best to run the processor intermittently (burst mode) rather than continuously.
- Reduce the clock frequency [3]. The higher clock frequency means that there is more switching so that more power is used by the transistors in the microcontroller.
- Use the low power modes of the microcontroller [3]. Most microcontrollers have a low power mode that will draw μA of current hence prolonging the battery charge.
- Disable any unused subsystems. The microcontroller is built for general use and contains many subsystems such as I2C, SPI, ADC, UART, GPIO etc. By turning off the subsystems that are not in use then they will not draw any power hence reducing the power drain. This is akin to switching off the lights in rooms that are not being used.
- Minimise the usage of the radios (Bluetooth, wifi etc). In order to transmit these will draw more power.

There are a number of procedures that can be performed to reduce the software power drain:

- Write the code to take advantage of power modes and turn off unused subsystems.
- Write the code to use interrupts rather than polling. This allows the microcontroller sleep modes to be used.
• Design the algorithms to reduce the computational complexity. The higher the computational complexity the longer time the processor is running hence more switching is occurring which uses more power.

**Case Study:** Commonly used classification algorithms were examined for their suitability for Wearables with the aim to determine their effect on the power usage [4]. The supervised classifiers had to distinguish between walking, running, stair ascending, and stair descending from data gathered by an IMU mounted on the foot [4]. The time taken to execute the classifier algorithm was taken as the metric since this is related to the power usage [4]. This analysis was performed on a typical Desktop PC using the MATLAB numerical language. Figure 1 shows the timing results for the different classifiers.

![Figure 1 The time taken for the 1000 runs of the different classifiers in milliseconds [5].](image)

**Discussion and Conclusion:** This paper noted that a desirable aspect for Wearables is to have a long time between battery recharging. The power drain on the battery is related to both the hardware and the software so they must both be taken into account when designing a Wearable device. This paper gave a number of suggestions that can be used to reduce the effect on the battery drain from the hardware and the software. A key aspect of the software is to carefully design the algorithms used.

A case study was presented for the comparison of typical activity classifier techniques for a foot mounted sensor. Table 1 gives the time taken for the typically used classifier algorithm types. The results are as expected where the least computationally complex algorithms use less time to compute and the more computationally complex algorithms use more time to compute. Therefore for the desired accuracy, the least computationally complex algorithm should be chosen to reduce the effect on the time between battery recharges.

**References:**

Microwave Imaging for Biomedical Applications

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Keywords: Cauchy integral, electromagnetic radiation, inverse scattering, microwave imaging

Extended Abstract. The application of electromagnetic radiation in its various forms as a means of obtaining useful diagnostic information in a non-invasive fashion is exploited from the lowest frequencies with impedance imaging [1] to the highest frequencies with X-ray computed tomography (CT) [2]. In imaging it is often believed that the resolution of the images produced is limited by the size of the wavelength of the radiation. That may be the case for some techniques but it is by no means a fundamental limit. For example, in the case of impedance imaging the wavelength of the radiation is many times the size of the object under scrutiny but useful images showing structure detailed within such objects are indeed obtained [3]. However the resolution is not as good as for X-ray CT where higher frequencies are used. In spite of somewhat lower resolution, imaging at the lower electromagnetic frequencies is attractive firstly because the photon energy is below the threshold for ionization, thereby eliminating the adverse health affects of ionizing radiation, and secondly because the cost of the technology is typically much lower. With ever improving technology both in terms of the analogue components and circuitry available for data acquisition, and in terms of the computational hardware available for image reconstruction there has of recent times been a resurgence in interest for exploiting the intermediate frequencies occupying the microwave range of the electromagnetic spectrum [4]. There is widespread effort to develop effective microwave imaging systems for application to diagnosis of breast cancer [5], greenstick fractures [6], intracranial bleeding [7] and osteoporosis [8].

From a theoretical viewpoint most methods used to reconstruct images from microwave radiation either transmitted through or scattered from an object of interest require a model of the way the electromagnetic radiation interacts with the material of which the object is composed. A popular mathematical model are the equations developed by Maxwell [9] as a description of most classical electromagnetic phenomena. Maxwell’s equations are suited for calculating directly the radiation transmitted or scattered when the material properties are already known, but are not in a form suitable to make the inverse calculation so easily. One approach is to make a first estimate of the material properties then to refine the estimate iteratively by repeatedly calculating the corresponding transmitted or scattered radiation and making adjustments to the estimate as necessary according to how well the calculations match the actual measured data. For this approach to be successful it is necessary to adopt a technique for calculating the scattered radiation which is highly efficient.

Calculating the scattered radiation from Maxwell’s equations is usually treated in terms of a set of four first order partial differential equations, often converted for simplicity into a second order ordinary differential equation. It has however been shown recently [10] that it is possible to take another path and convert the four first order partial differential equations into a single first order ordinary differential equation. The solution of first a single first order ordinary differential equation is of course much easier and more efficient that the solution of either a second order ordinary differential equation or a set of four first order partial equations. For the application of microwave imaging to biomedical and other applications where efficiency is paramount there is a strong imperative for adopting the newer approach.
The newer approach is implemented in the framework of Clifford algebra [11]. Although unfamiliar to many, ultimately this is easier than the traditional approach of using vector calculus [12]. The new approach author leads to a solution in terms of the Cauchy integral [13] in its multidimensional form [14], rather than as conventionally [15] in terms of integrals involving Green’s functions. This approach has already been properly validated in one-dimension for materials of all types [16], and in two dimensions initial successes have been reported [17]. Although the new method is similar to the traditional approach in that they both solve a linear system of equations, the method is sufficiently different to offer an implementation which avoids calculating most of the elements of the corresponding matrix. Not calculating most matrix elements is a huge saving in term of computational effort. Rather than inverting a matrix the method, known as the Clifford-Cauchy-Dirac (CCD) technique [10], finds the solution iteratively in as few as twenty iterations using projections defined from the Cauchy integral, onto convex sets [18]. The conventional method simply cannot do that because it is not based on the Cauchy integral, and for that reason cannot achieve the same computational efficiency.

Based on its computational efficiency the CCD technique is ideally suited for the purpose of reconstructing diagnostic biomedical images from microwave radiation.

References


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Novel Robust Sensor for Intraoral Bite Force Measurement in Human Subjects

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Keywords: bite force; strain gauge; stainless steel; oral health.

Extended. Maximum Bite Force (MBF) measurements can be utilised by professional dentists to assist in the diagnosis of a patient’s oral health. MBF measurements are also commonly used in the design, rehabilitation, and evaluation of oral prosthetics and implants. Griffith University’s School of Dentistry and School of Criminology and Criminal Justice submit a request for a 250 to 550 N measurable range intraoral bite force sensor that is safe for use in both research and dental analysis. Based on the conceptual design, a sensor prototype was designed and implemented using 420 stainless steel and conventional milling process. The sensor was more compact and robust compared to the acrylic prototype [1], and lower cost than silicon micro force sensor [2].

Sensor Design and Simulation

Structure of the sensor is shown in figure 1 (a), consisting of two metal pieces and a metallic strain gauge bonded together using cyanoacrylate epoxy. Protective casings made from a Poly-Vinyl Siloxane (PVS) addition silicone material commonly used in dentistry to make impression moulds of a patient’s teeth, meaning the material is well tested and considered safe for intraoral use. The PVS material is a robust silicone with excellent electrical resistive properties. When a bite force is applied on the sensor, the upper plate will be deformed, leading to the change of resistance of the strain gauge bonded to it.

Figure 1 (a) shows the sensors structure, with an overall size of 10 mm x 10 mm x 5 mm. Structural simulation in Solidworks™ Simulation (2015) indicated that 440C stainless steel would be capable of withstanding a total of 1300 N before plastically deforming. However, 420 stainless steel was chosen due to its better availability in Australia. Using the same sensor design, 420 stainless steel yields at approx. 300 N in simulations. The estimated measurement range of the sensor has thus been reduced to below 23% of its initial 1300 N limit.

Fabrication and Characterisation Results

The sensor prototype was fabricated out of 420 stainless steel at Griffith University using a 3-axis manual milling machine. The sensor went from a single piece of acrylic to layered stainless steel plates that had to be held together with epoxy. Due to this, the application of the sensing element (strain gauge) was made much easier than the acrylic prototype. The final prototype’s structure was modified to reduce size and number of layers to two, while maintaining the benefit of being able to easily bond the strain gauge to the sensor. The assembled sensor can be seen in figure 1 (b).
Calibration and testing is performed using an Instron universal testing machine in order to make accurate and reliable comparisons between applied forces and sensor output. Calibration measurements are performed using a Wheatstone bridge and a voltage amplifier (AD 623) connected to an oscilloscope (MSO-X 3104A, Agilent Technologies, California, United States). A custom designed circuit and software package capable of simultaneously reading, displaying, and saving the data from the sensor in real-time on a connected computer was created for use in practical testing. A Sparkfun HX711 and Arduino Pro Micro were used to provide a means to easily calibrate and tare the sensor with software, allowing the circuit to produce readable force values without performing manual conversions. Three human volunteers provided preliminary practical test data (GU Human Ethics Protocol 2016/142), resulting in bite forces within the expected range derived from literature (≤ 700 N) [1]. Linearity and repeatability of the sensor was improved over the acrylic prototype [1]. Despite the effective measurable force of the sensor being limited, the third prototype provide exceptional results from the calibration process up to 300 N as seen in figure 1 (c).

Throughout the calibration and testing phase, it was noted that the sensor design would also be suitable for other applications. Such applications include using the sensor in an array to perform multi-point measurements (not limited to bite forces). The sensor could be effectively applied in robotics due to its small size, high sensitivity, and modular functionality. An example of this would be to use the sensor as haptic feedback to give robotics a highly effective and low-cost sense of touch.

![Figure 2](image.png)

**Figure 2.** (a): CAD design of the sensor. (b): Assembled sensor with protective casing. (c): Calibration results of the sensor.

**References**


Assessing the impact of integrating IMU wearable technology in an elite netball training environment for performance analysis

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Introduction: Since its codification in 1901[1], netball has become increasingly popular with a current playing population in excess of 20 million players [2]. The core aim of netball is for the goal shooters to shoot the ball through a 3.05m high pole, with the team who scores the most goals at the end of four 15 minute quarters winning the game. Subsequently, scoring has been deemed the most important facet for competitive success of a netball team [2] with an impetus tracking shooting percentages both in training and match environments. In high performance environments shot tracking is generally manually recorded, a resource intensive process occurring both in training and game environments. Recent advancements in technology, paralleled with an increased professionalism within netball has led to new methods of performance analysis. Video analysis [3], inertial sensor for workload intensity based classification [4], and GPS for load monitoring [5] have been reported in literature as novel methods for performance analysis. The advent and increase in popularity of crowd funding has led to a plethora of wearables based on inertial measurement units (IMUs) being taken to market. One such device is the ShotTracker (ShotTracker, Kansas City, United States of America), an IMU based basketball shooting unit, designed to automate the tracking of basketball shooting percentages [6]. ShotTracker gives concurrent knowledge of results in terms of shooting percentages, however there is no evidence in netball literature confirming the effectiveness of this feedback in netball shooting.

Methods: Two elite female shooters (20yo, right handed) from an elite grade netball team were chosen to participate in the study. The participants were the primary shooters for the same national representative team, playing at an international netball competition which consisted of 6 games. One player as the primary Goal Shooter (GS) and the other as the primary Goal Attack (GA). The study was to assess whether utilising automated shot tracking in training would improve accuracy in game. Three periods were examined, a control period of five weeks of state level based games with no technology, an intervention period where shot tracking was used for five weeks, and finally the international match period, consisting of 6 international matches. The intervention encompassed the coaching staff using the ShotTracker system during specific shooting sessions. The coach, utilising the iPhone application, had access to constant knowledge of shooting percentages during the shooting session and delivering verbal cuing to the player when they deemed appropriate. Prior to this study neither of the players or the teams coaching staff had used technology to automate shot tracking. The ShotTracker system was set up as per the manufacturer’s instructions with the wrist sensor, encased in a sweat band, mounted proximal to the distal radioulnar joint and a second, net mounted sensor, clipped onto the net[6]. The beginning of the intervention period included a baseline shooting test to validate the technology. This test encompassed a 10 minute shooting warm up followed by 10 shots from a mid-range distance (2.45m from the goal post) at three locations, directly in front of the post (0°), 69.7° to the left of centre, and 69.7° to the right of centre. On the 7th shot of each block, the coach put defensive pressure on the shooter with a pool noodle shown in Figure 1. As an independent validation, the thirty shots for each shooter were filmed and the result
of the shot was recorded by a researcher blinded to the ShotTracker outputs. The research was conducted under Griffith University Ethics (GU:2016/294).

**Results:** The validation test showed consensus between the manually recorded and automated shooting outcomes, with both indicating that 54/60 shots were made. During the intervention period 7 sessions were tracked, with the ShotTracker automatically tracking 686 goals from 906 attempts at a mean shooting percentage of 75.72%. The shooting percentages for the state league and international games are shown below.

![Figure 1. (Left) Tabulated field goal percentages over the three periods. (Right) Image showing the 7th shot from the centre position.](image)

<table>
<thead>
<tr>
<th>Shooter 1</th>
<th>Shooter 2</th>
<th>Av.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>Attempts</td>
<td>%</td>
</tr>
<tr>
<td>Pre Intervention</td>
<td>134</td>
<td>168</td>
</tr>
<tr>
<td>Intervention</td>
<td>50</td>
<td>57</td>
</tr>
<tr>
<td>Int. Competition</td>
<td>128</td>
<td>151</td>
</tr>
</tbody>
</table>

**Discussion:** Although the technology was validated without error, the coaching staff reported an error if there was a goal post collision, where the vibrations were sufficient enough to shake the net mounted device. When this occurred the coaching staff manually adjusted the ShotTracker attempts and goals. Shooting percentages, as shown in Figure 1, improved after the ShotTracker was used. Interestingly this improvement happened irrespective to the elevation in competitive defensive pressure inherent with the increased competitive standard of the international competition. It should be noted that the authors don’t feel the improvements should be entirely attributed to the knowledge of results provided by the automated tracking system. The nature of being tracked will invariably increase practice pressure, increasing athlete accountability and ensuring shooting targets are adhered to. Furthermore, both the athletes and the coach reported the enjoyment of utilising technology, essentially gamifying the training environment. With higher practice it could be reasoned that shooters will more likely engage in a higher frequency and duration of deliberate practice, potentially enhancing skill gains. Furthermore, this study is limited by a small sample size an inherent issue when there are only two primary shooters in an elite team.

**Conclusion:** The results indicate that the accurate automation of shot tracking in netball training is possible using wearable IMU technology. Marginal performance gains, in relation to shooting percentages, were noted however a direct correlation between this and automated shot tracking cannot be made solely from this study.

**References:**


Human-Machine Interaction (HMI) is ubiquitous; picking up a mobile phone and searching for a nearby restaurant or sharing an image through social media is carried out without a second thought. It is part of daily life. HMI has recently emerged as a research discipline in its own right as the complexities of interactions, and their impact not only on products’ performance, but on human development itself, is beginning to be more fully understood. "HMI, as a field of investigation, is quite recent even if people have used machines for a long time. HMI attempts to rationalise relevant attributes and categories that emerge from the use of (computerised) machines. Four main principles, that is, safety, performance, comfort and aesthetics, drive this rationalisation along four human factors lines of investigation: physical (that is, physiological and bio-mechanical), cognitive, social or emotional." The challenge for designers, and indeed the education of design students, is making sense of these broad technical and emotional requirements within a single unified product or service.

Traditionally, industrial designers develop the physical form and function of a product, and engineers and information technology (IT) specialists develop the internal electronics that connect the product to the internet or power electromechanical movements or sensors. Whilst all parties may meet the requirements of the design brief, a traditional, isolated approach to the development of each element can lead to fractured product outcomes. This is because disjointed elements can be merged together at the end of the design process, rather than developed simultaneously in a collaborative fashion. This can lead to human-machine interactions where the use of the product and the electronics of that product that do not effectively work together to create a seamless experience for the user, fully designed to be in sync with daily human activities. However, this is changing, as industrial design students are increasingly being "re-coded" to be able to simultaneously develop the hardware and the software for HMI products. This is possible because of the emergence of Visual Programming Languages (VPL’s) that can replace traditional text-based coding methods. A VPL can be likened to a two-dimensional representational diagram with visual blocks and linking connectors rather than strings of text.

Griffith University introduced a core course for industrial design students called Human Machine Interfaces in 2015 to respond to the new opportunities to better engage the students in the development of electronics-based products. In this course, accessible, open tools, such as Arduino microcontrollers, allow students to rapidly generate creative, advanced prototypes. These can be completed to working model stage within the space of two six-week projects. While it was previously possible to engage the students with introductory learning about electrics and electronics within that time frame, there was little space for students to engage with the design opportunities and the outcomes tended to be predictable and low level in design terms. VPL’s allow for a different way of working that enables design-led development, rather than outcomes limited by conventional electronics.

Grasshopper VPL has been chosen as the main mode of programming and interacting with the Arduinos. In the Griffith University example, the first three weeks of the course teaches both the more common text-based coding method as well as Grasshopper to allow students to make their own
comparisons and understand some of the logic behind programming. At the conclusion of the first three weeks of the 2015 course, an anonymous survey was completed by the industrial design students about their experience and understanding of coding with both methods, with the results published by Novak and Loy\textsuperscript{2} clearly indicating a preference for the Grasshopper VPL. In fact given a hypothetical design brief, one-hundred percent of respondents indicated they would prototype using Grasshopper over a text-based tool. This is in line with similar research conducted by Celani and Vaz\textsuperscript{4} who had success with Architecture students and VPL’s, indicating that the inherent visual skills of creative designers allows them to more rapidly and easily adopt VPL’s rather than traditional coding.

What is significant about such research is that new approaches to programming mean that design education can maintain its focus on user-centered principles, rather than being derailed by a requirement to train designers to code using text-based systems in isolation from the design process. By using VPL’s, design students now have the capacity to rapidly prototype both the physical and electronic aspects of their design. This means they can be iteratively developed as holistic solutions to a design brief, and represents a paradigm shift from the previous process where designers were dependent on the technical expertise and perceived limitations of technicians from traditional disciplines. As a result, rather than focusing only on the physical design and showing minimal understanding of the technical systems to make their product work, industrial designers have the potential to produce design-driven outcomes where the electronics is integral to the design thinking embedded in the product, rather than integrated into it.

As a tool for empowering designers, Visual Programming Languages are proving to be effective within the industrial design course at Griffith University, and student feedback to the opportunities they provide has been positive. Whilst text-based coding will likely remain the best method for programming large interconnected systems and complex software, industrial designers who are not necessarily interested in becoming programmers are for the first time able to genuinely integrate electronics into their design process. The role of the industrial designer is broad, encompassing ergonomics, user experience, aesthetics, form, manufacturing constraints and much more. The complexities of programming languages restrict the thinking and creativity of a designer when responding to a complex, human-centred design problem. VPL’s are changing the game. They are providing designers with workflows more akin to other visual practices already common to the design process, allowing them to remain creative and design-led, whilst engaging more fully with the interaction design elements of their product. Designers are beginning to see “code as a kind of material just as a potter sees clay.”\textsuperscript{5}

References


Modelling resistance exercise lifting technique with inertial sensors: Knee extension during deadlifts

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Keywords: Wearables, Resistance exercise, Inertial sensor, Technique, Knee extension.

Introduction

Biomechanical models provide insight into the constructs of resistance exercise, allowing health professionals to ensure lifting technique is safe and efficient. Defined from past kinematic research, the deadlift has been modelled with inertial sensors to have three separate phases during the lift [1]. These phases include the lift off phase (LO), knee passing phase (KP), and the lift completion phase (LC) [2]. Analysing biomechanical models with wearable technology may provide tools for health professionals to identify injury risks and provide accurate feedback to clients. Inertial sensors have been used to accurately classify resistance exercise technique into categories based on expertise with greater accuracy than professional observation [3]. The aim of this research was to model deadlift technique with inertial sensors to interpret trends of movement patterns.

Methods

11 Volunteers performed unweighted conventional deadlifts for two sets and five repetitions per set (Charles Darwin University Ethics Committee clearance: H14046). Lifting technique was instructed by a qualified strength and conditioning coach. One set was performed with simultaneous knee, hip and spine movement and one set was performed with knee extension occurring as the primary initiator of movement. Volunteers were monitored with tri-axial inertial sensors (SABEL sense) located on the skin at the Cervical (C7), Thoracic (T12) and Sacral (S1) spinal landmarks [4]. A five Hertz low pass filter was applied and the concentric phase of each lift was time normalised (N=100). Students T tests were used to compare the difference of gyroscope Y axis rate of change group means, due to this data representing spinal movement in the sagittal plane. Group means were modelled to cross reference video playback for interpreting real world trends.

Results

A null hypothesis of no significant technique rate of change difference was rejected for the relationship at the sacral spine (Table 1).
Table 1. Knee extension rate of change difference

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL UW C7 vs. KneeExt C7</td>
<td>0.525</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>DL UW T12 vs. KneeExt T12</td>
<td>0.592</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>DL UW S1 vs. KneeExt S1</td>
<td>0.169</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Legend: DL = Deadlift; UW = Unweighted; KneeExt = Deadlift with knee extension occurring first; C7 = Inertial sensor at cervical spine; T12 = Inertial sensor at thoracic spine; S1 = Inertial sensor at sacral spine.

Figure 1. Sacral spine (S1) degrees per second model comparison between typical unweighted deadlifts (DL UW S1) and deadlifts with knee extension as the initiator of movement.

Discussion

Results suggest a significant measurable difference between the two lifting trials if measured from the sacral spine. This may be due to isolated or greater knee extension as the initiator of movement leading to larger hip displacement whilst the spine remains neutral [1]. As defined from past research for hip and knee rate of change, spinal rate of change models can be classified into the same three phases (Figure 1) [2].

Figure 1 demonstrates the clear differences of the three phases between trials with simultaneous movement and isolated knee extension, specifically the KP phase. Therefore, it was concluded that inertial sensors can model the three phases of a deadlift from S1 and may be able to identify if knee extension is occurring as the primary mover. This may have significant impacts for health professionals feedback to clients for skill acquisition in amateurs, and safety or equilibrium for spinal and knee loading. Various other techniques and resistance exercises may be interpreted with similar methods to assist health professionals feedback. Resistance exercise risk factors to injury which inertial sensors may be capable of monitoring include joint angles, posture, speed of movement, displacement, fatigue, and power. Future research is needed to develop dynamic biomechanical models of resistance exercise which can be monitored in real time with user friendly automated inertial sensor method designs. Such research could have a large impact on numerous societal areas.
including workplace health and safety, recreational exercise, health and rehabilitation, physical activity classification, and professional sport.

References


Progress in Metal Additive Manufacturing towards a Wide Implementation in Dentistry

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Keywords: Selective Laser Melting, Laser Polishing, Anisotropy, Biocompatibility, Dental Alloys

In recent years, the availability of high power lasers has enabled the full melting (FM) of raw materials, as in the case of selective laser melting (SLM), and hence, has overcome the necessity of a binder [1]. Thus, the FM allows the fabrication of parts with alloys suitable for dental applications. SLM eliminates many physical stages, required in the time-consuming investment casting process, by offering speed of the manufacturing process for bespoke metallic devices, such as denture frameworks and implant abutments [2-5]. The manufacturing process is solely based on dental and medical CAD data, which are designed on virtual anatomical patterns received from high-resolution dental scanners and CT, CBCT, MRI, photogrammetry, or surface scan data [6,7].

Cobalt-chromium (Co-Cr) and titanium alloys remain by far the most widely used alloys for affordable prosthodontics treatment. Documented studies show SLM fabricated parts possess adequate mechanical properties for clinical use [8-10]. In addition, available data indicates superior properties, in comparison to cast, for both tensile strength and fracture toughness [4,11-13]. These results show that a direct substitution of investment casting with SLM in the dental area is uncritical. In the assessment of biocompatibility, corrosion data, which forms an excellent adjunct to cytotoxicity studies, show that SLM fabricated samples have lower ion emission rates than cast ones (Fig. 1) [2,4]. Cytotoxicity studies also proved them safe, non-irritant and nontoxic on oral tissues and the body as a whole [14,15].

However, the design and dimensioning of components can be very challenging, as the layer-wise generation process results in anisotropic material properties, which are highly volatile to the manufacturing conditions [16]. For components designed close to the material limits, the dimensioning state has to account for the anisotropic properties, in both, the elastic and elasto-plastic range, including the stress-concentration effects of localized, inherent imperfections [17]. Currently, the surface roughness of ‘as-built’ SLM parts appears of insufficient quality for dental applications [18]. It is worth stating that the particular surface characteristics, and consequently their roughness, depend on the alignment and the positioning in the built space [19]. The choices available in post processing technologies to overcome the challenges of insufficient surface quality, while still maintaining the geometric flexibility in the built parts, are limited. On a positive note, recent studies have advanced from a proof of concept stage to polish the surface of SLM components with a laser; a process that could eliminate manual polishing altogether [20,21].
Conclusion

The SLM process, although high-priced to acquire, offers increased speed and flexibility in dental technology. Likewise, the SLM process, being controlled digitally, offers a standard method for the production of dental devices, which is likely to be much closer to the manufacturer’s specifications than investment casting that is fraught with fabrication steps and operator variations. Nevertheless, further studies are required to understand the parameters that influence the physico-mechanical properties of SLM fabricated components.

References


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Using Inverse Finite Element Simulation to Characterise Soft Tissues by MSC Marc/Mentat

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**Keywords:** Inverse finite element analysis, Depth-Sensing Indentation Test, Thin Film.

**Extended Abstract.** The study of materials is connected to a framework comprising of four inseparable elements: processing, mechanical properties, characterization, and theory [1]. Changing the process path of manufacturing results in altered mechanical properties which require a theory to be justified. Meanwhile, characterization provides the insight to the multi-scale structure of the material. Generally, characterization of classical materials such as metals, ceramics, and polymers can be readily done by conventional materials testing methods such as the tensile test, the torsion test, and multi-axial tests among others. Although monolithic materials cover a wide range of applications, generally non-homogeneous anisotropic materials are created to perform under many critical cases. The non-uniformity of these rather complex materials can also be characterized, to some extent, using the classical tests. A higher level of complexity can be found in the hierarchical structure of soft tissue which consists of interconnected multi-level structures. Approaching non-conventional materials with classical material tests makes the characterization process cumbersome, if not impossible. This demands for new methods of characterisation.

A very attractive alternative to the classical experiments is the depth-sensing indentation test which is preformed, in its very primitive form, as an indentation hardness test. Although the original depth-sensing tests were carried out using the Berkovich indenters, other axisymmetric indenters can also be used [2]. Furthermore, the beauty of the indentation test is the fact that it can be implemented in macro-, micro- and nano-scale levels which makes it an appropriate tool for multi-scale applications. More recently, a new type of indenter, i.e. the lateral cylindrical indenter, was proposed to characterise structured material, e.g. a porous structure. In addition, the possibility of using AFM to conduct experiments using the mentioned particular cantilever is considered [3, 4]. Nevertheless, the nonlinear nature of such contact problems limits the derivation of a closed-form analytical solution almost impossible for many cases. Approaching the problem numerically also raises complexity because of the required iterations for numerically solving nonlinear simultaneous system of equations [5, 6]. The widely known numerical method for the solution of partial differential equations is the finite difference method which is now an alternative to the mainly used numerical method, i.e. the finite element method [7]. Finally, the finite element method, is selected as the computational tool of this investigation since analytical solutions are not available for such a multi-parametric contact problem that is faced in the indentation of materials.

Generally in a finite element simulation, most of the parameters regarding the FE model are known and the user is looking for the results of the simulation, e.g. deformations or stresses. In contrast, in the inverse finite element method, an ordinary FE model is coupled with an optimisation algorithm. The goal is to find the optimal target parameters of the model which corresponds to the correct behaviour of the model. These target parameters are incorporated into a user-defined objective function which is used to measure the degree of optimality of the target parameters (see Fig. 1). Target parameters are either physical quantities such as the geometry of the model in a topology optimisation problems, or material parameters in parameter estimation problems. In any case, choosing the target parameters must be done carefully [8].
For an inverse FE solution, extra programming, or at least scripting, will be required in addition to a typical commercial FE package. Nevertheless, such level of complexity demands a powerful package to handle the simulations. The MSC Marc/Mentat semi-open commercial package is selected to carry out the analyses. More flexibility is obtained by incorporating the user-defined FORTRAN programming language code into the software [9].

Although Marc/Mentat provides many facilities for nonlinear simulations by default, there are a few parameters which cannot be directly calculated—especially in contact problems. For instance, the contact area cannot be calculated by the software. The solution for such problems is presented in [7] where a rather extensive package of ready-to-use subroutines (more than 50) has been made available for users. The result is a great versatility in terms of defining customized material properties, boundary conditions, contact properties, and elements which makes the validation of the experimental results possible.

References

Fused deposition modeling of 3D parts using acrylonitrile butadiene styrene (ABS) polymer

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Keywords: Acrylonitrile butadiene styrene polymer, disordered solids, mechanical properties of solids, mechanical properties anisotropy, fused deposition modeling

Extended Abstract. Anisotropic mechanical properties of parts fabricated using acrylonitrile butadiene styrene (ABS) polymer relative to part built orientation employing fused deposition modeling process is reported. ABSplus-P430 polymer was used to investigate the effects of infill orientation on parts mechanical properties under tensile and compression loading. The results revealed that infill orientation strongly affects tensile properties of fabricated ABS samples, namely the values for Young’s modulus were found to be ranging from ~1.5 to ~2.1 GPa, ultimate tensile strength from ~12.0 to ~22.0 MPa, yield strength from ~1.0 to ~21.0 MPa and elongation-at-break from ~0.2 to ~4.8 % for different infill orientations. Samples with infill orientation aligned to the vertical (i.e. Z-) axis were found to display the highest values relative to all other infill orientations studied. Mechanical properties anisotropy was lower for parts under compressive loading, that is the Young’s modulus, ultimate compressive and yield strength were weakly correlated with infill orientation apart from samples those built orientation was aligned at 45° to the vertical Z-axis. The latter samples displayed inferior mechanical properties under all compressive tests. The effects of sample gauge thickness on tensile properties and ABS sample micro- and bulk- hardness with respect to infill orientation are also discussed [1].

References
