An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications

DAVID RUSHTON-SMITH
david@rushton-smith.com

ANDREW WING KEUNG TO
andrew.to@student.uts.edu.au

GAVIN PAUL
gavin.paul-1@uts.edu.au

DIKAI LIU
dikai.liu@uts.edu.au

Faculty of Engineering and IT, The University of Technology, Sydney, Australia

This paper presents an approach for frequent hand-eye calibration of an Infrared (IR) range camera mounted to the end-effector of a robot manipulator in field applications. Currently, an existing approach has demonstrated the cost-effective use of reflector discs to detect distinct feature points for hand-eye calibration. In this paper, the approach is further improved to increase the accuracy and reliability which are both necessary for practical field use. The improvements include a morphological operation in reflector disc detection, an averaged hand-eye transform from strategically selected camera viewpoints, and a fault recovery procedure. Experimental results show that the proposed approach is able to increase calibration accuracy by 18 times and can be reliably used in the field by an inexperienced operator.

1. Introduction

In autonomous field robotics, it is common to mount sensors onto a robot platform to enable geometric mapping of the surrounding environment. For a bridge maintenance system that uses a robot manipulator to autonomously grit-blast steel surfaces [1] [2], an IR range camera can be mounted onto the end-effector of the ma-

Proc. of the 3rd IFToMM International Symposium on Robotics and Mechatronics (ISRM 2013)
Edited by I-Ming Chen, Marcelo Ang, Guilin Yang, Kin Huat Low and Albert Causo

ISBN: 978-981-07-7744-9 :: doi:10.3850/978-981-07-7744-9_045

nipulator to perform mapping of the environment [3]. The IR range camera captures depth data instantaneously over a wide field of view and is well suited for a harsh and dimly lit environment, such as a bridge structure. In order to fuse the depth data into a global map, hand-eye calibration is performed to identify the transform between the IR range camera and robot coordinate frames.

Frequent hand-eye calibration of an IR range camera in a bridge maintenance application is required when the IR range camera is to be detached and reattached for different maintenance operations, cleaning or replacement. However, it is infeasible to relocate the robotic system into a precisely controlled environment every time re-calibration must be performed. Therefore, hand-eye re-calibration needs to be performed in-situ at the site of maintenance by inexperienced operators while keeping setup time and necessary equipment to a minimum. A simple yet reliable approach to hand-eye calibration in the field is necessary such that the robot can be returned to normal operation with minimal operational delay.

In robotic systems, hand-eye calibration identifies the relative transform (translation and rotation) between the camera coordinate frame and the robot end-effector coordinate frame. Hand-eye calibration is commonly performed using feature point correspondence techniques to simplify the problem into matrix equations [4] [5]. 2D feature point correspondence for hand-eye calibration of a camera can be performed using edge, corner and centroid feature points extracted from calibration images such as those containing known-scale checkered board patterns or circles [6] [7] [8]. Given the available depth data from an IR range camera, 3D point features can be used to improve precision and reduce the number of observations required. Point features can be extracted from edges and planes using depth data of either the sensed surrounding environment and/or a specially designed 3D calibration object [9] [10]. However, reliable 3D feature extraction in a dynamic and harsh bridge environment is still a challenge in order to enable automated and frequent in-situ hand-eye re-calibration. For example, the grit-blasting hose attached to the robot manipulator can occlude calibration features as the manipulator moves around to different viewpoints, and dust in the air can cause sensor readings to become unreliable. Thus, calibration approaches using distinct high contrast features have been investigated in [11] [3], which uses a projected laser pointer to generate a high-contrast features for stereo vision hand-eye calibration and reflector discs to create high contrast features for IR camera hand-eye calibration. The reflector discs approach to hand-eye calibration has previously been demonstrated in a controlled laboratory environment. However, in order to be acceptable for practical field use, further accuracy and reliability improvements are required.

In this paper several improvements are proposed for the hand-eye calibration approach present in [3], to increase the accuracy and reliability necessary for practical field use. The presented improvements include; morphological operations and blob filtering in the reflector disc detection algorithm, an averaged hand-eye transform from strategically selected camera viewpoints, and a method for dealing with spurious data. Overall, the proposed improvements further automates and simplifies the hand-eye calibration procedure to be usable by a field operator with no in-depth knowledge of calibration.

The paper is structured as follows; Section 2 presents an overview of the existing hand-eye calibration approach, while Section 3 describes the proposed improvements, including the morphological operation to improve reflector disc detection, the technique for viewpoint selection and hand-eye transform averaging, and improvements in fault tolerance. Section 4 presents experimental results and Section 5 concludes and discusses future work.

2. Background

The existing calibration approach [3] utilises the one-to-one correspondence between the relevant data structures available from the sensor in use (Fig. 1). The IR image is processed to identify features - the centroids of three reflector discs arranged in a structured pattern (Fig. 2*b*). Once the centroids have been determined, the corresponding 3D co-ordinates of each disc can be determined by reading the corresponding depth values from the raw depth map.

The location of these features in three dimensional co-ordinates relative to the robot base is static, and can be determined by moving a robot end-effector pointing tool to the location of each disc as described in [8].

The homogeneous transform matrix describing the location of the sensed feature locations in the camera frame f_i and the feature locations in the robot base frame f_i' can be computed using 3D feature point matching, where Singular Value Decomposition (SVD) is used to find the least-square fit with features $i = 1, 2, ...M$.

$$f_i' = {}^oR_s f_i + {}^ot_s + N_i \tag{1}$$

Here, ${}^ot_s$ is the translation vector, ${}^oR_s$ is the rotation matrix from sensor (s) to robot base (o), and N_i the noise vector. The least-square solution to ${}^ot_s$ and ${}^oR_s$

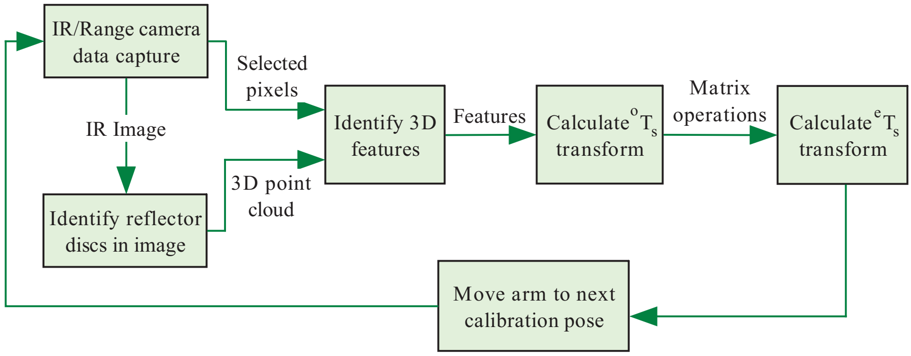
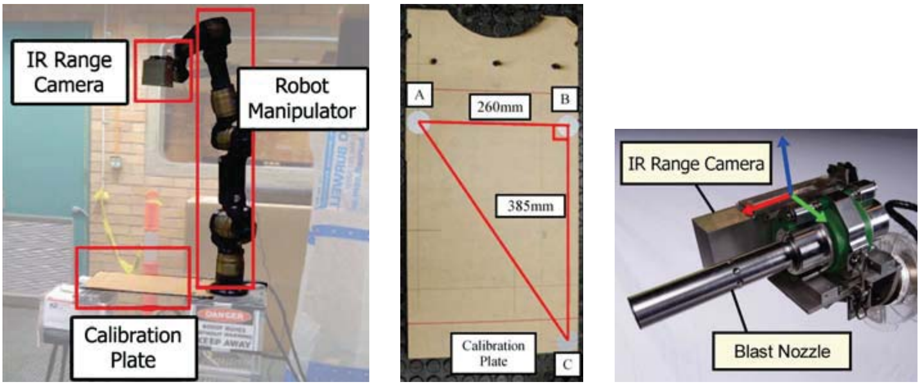


Fig. 1. Overview of the hand-eye calibration process.



(a) (b) (c)

Fig. 2. *a*) Observation of calibration plate by manipulator-mounted IR range camera; *b*) Close-up of calibration plate and reflector discs; *c*) Approximate location of the hand-eye transform matrix.

will then be the camera-to-robot base homogeneous transform ${}^{o}T_s$,

$$ {}^{o}T_s = \begin{bmatrix} & {}^{o}R_s & & {}^{o}t_s \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

The hand-eye transform ${}^{e}T_s$ can then be calculated. For any given robot manipulator pose, ${}^{e}T_s$ is constant between the end-effector (e) to robot base frame (o) and the camera (s) to robot base frame (o). Using the camera to robot base transform ${}^{o}T_s$ and the end effector to robot base transform ${}^{o}T_e(Q)$ calculated using forward kinematics based on the corresponding robot manipulator pose with joint angles, $Q = [q_1, q_2, ...q_6]^T$,

$$ {}^{o}T_e(Q) = \prod_{i=1}^{6} {}^{i-1}T_i(q_i) \tag{3} $$

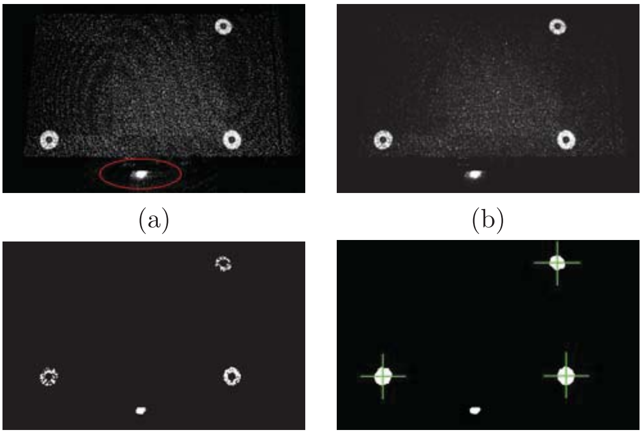
The hand-eye transform is then

$$ {}^{e}T_s = {}^{o}T_e(Q)^{-1} \times {}^{o}T_s \tag{4} $$

3. Improved Approach

3.1. *Disc Detection*

The existing approach for disc detection is based on the iterative use of a median filter for noise rejection [3]. A median filter is typically used for removal of ”salt and pepper” noise present in an acquired image [12], and so the usage of a median filter in this case is appropriate for removal of the speckle pattern created by the sensor’s



(a) (b)

(c) (d)

Fig. 3. *a*) Raw IR image, artifact highlighted; *b*) Median filtered; *c*) Thresholded binary image; *d*) Closed binary image with disc locations computed.

IR projector. This approach however, is unable to remove more complex artifacts present in the IR image. Such artifacts may include highly-reflective bolt-heads located on the robot itself, as well as other items found in the field environment such as reflective aluminium beams (Fig. 3*a*).

The improved approach utilises morphological operations with blob detection and subsequent filtering as follows

(1) Apply a median filter in order to remove the dot speckle pattern created by the sensor's IR projector (Fig. 3*b*).
(2) Apply intensity-based thresholding, in order to produce a binary image which shows pixels with high IR reflectance (Fig. 3*c*).
(3) Apply an image-close morphological operation (that is, erosion followed by dilation) so as to round-out the blobs detected, fill in the center of the discs, and remove remaining speckle noise (Fig. 3*d*).
(4) Apply blob filtering in order to identify the discs within the remaining blob set. Blobs are sorted and rejected according to area, as well as eccentricity.

Given that blob area and eccentricity (circularity) are reasonably consistent between calibration trials, these attributes provide reliable thresholding criteria for successful object detection.

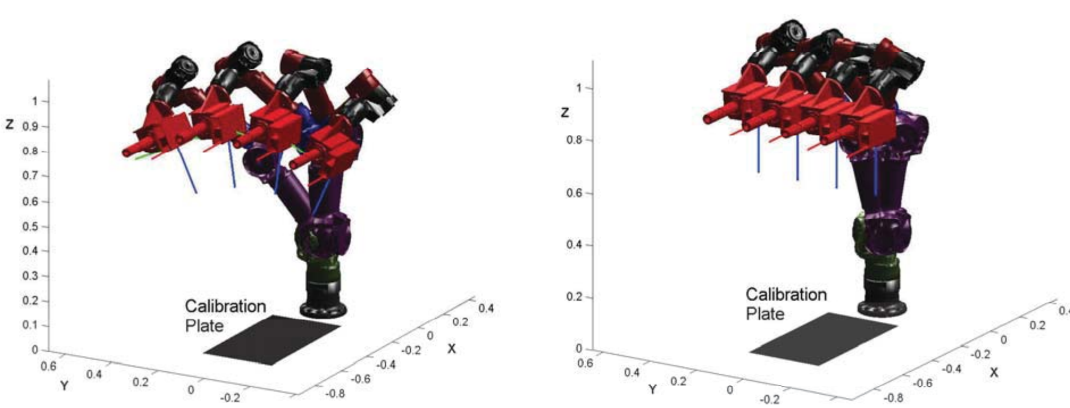
Table 1. Homogeneous transform matrix utility functions.

Name	Definition
transl	Extract translational components
itransl	Construct transform matrix based on translational components
rpy	Extract rotational components (roll, pitch, yaw)
irpy	Construct transform matrix based on rotational components (roll, pitch, yaw)

3.2. *Multiple Viewpoint Generation*

Instead of calibration from a single viewpoint [3], for improved calibration accuracy multiple robot configurations (poses) can be established such that the sensor can observe the calibration plate from a number of viewpoints. The robot moves through the array of poses, and a calibration transform matrix is computed at each. Upon completion, the final transform matrix ${}^{e}T_{s,f}$ can be computed as the mean translation and rotation of all transform matrices ${}^{e}T_{s,i}$, from $i = 1, 2, ...M$, where Table 3.2 describes the utility functions used

$$T_f = itransl\left(\frac{1}{N}\sum_{i=0}^{N} transl(T_i)\right) * irpy\left(\frac{1}{N}\sum_{i=0}^{N} rpy(T_i)\right) \tag{5}$$



(a) (b)

Fig. 4. Robot shown in multiple poses. *a*) Sensor viewpoints are equally rotated about the X axis; *b*) Sensor viewpoints are equally translated along the Y axis.

The use of multiple viewpoints has the advantage that any error present in a single plate observation (caused by a localised abberation in the depth values at this location) is mediated by the remaining plate observation transform matrices. Minimising rotational errors is particularly important since a small rotational error introduces large errors at longer distances from the sensor, when transformed into the base co-ordinate frame.

In order to observe the plate from multiple viewpoints, an array of robot poses is generated using inverse kinematics. For maximum observation variation, the viewpoints are calculated such that they are evenly spaced along each dimension, as well as evenly rotated about each dimension (X, Y, and Z). Fig. 4 shows a subset of the viewpoints used. For purposes of brevity the full range is not shown.

3.3. *Improved Fault Tolerance*

Due to the unpredictable field environment in which the robot is calibrated, there are several disturbances to the calibration process that may be experienced, including dust in the air, or unexpected objects within view of the sensor. Thus, possible sources of error must be anticipated and accounted for in advance, to ensure that the calibration process can run smoothly. The process checks for the following events

- Incorrect number of calibration discs detected
- Calibration discs out of view
- Incorrect/unavailable depth values on calibration discs
- Unsuccessful 3D feature matching
- Triangle edge length falls outside of tolerance range

For all such outcomes, the algorithm abandons the transform computation at the current robot pose and discards all related data. The robot then moves onto the next pose, and the calibration process continues.

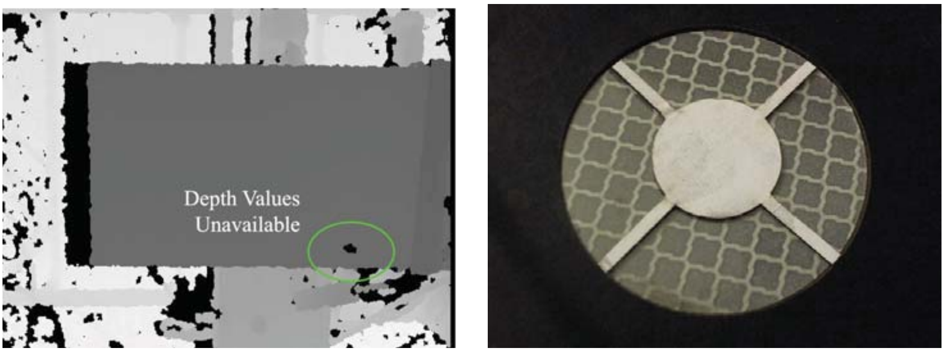
3.4. *Depth Value Availability*

In the existing calibration approach, at close viewing distances a depth reading is not achievable in some cases due to the high reflectance of the discs (Fig. 5a). This is a known limitation of the class of sensor in use [3]. Fig. 5b) shows how this limitation has now been overcome via the addition of a small concentric non-reflective disc, placed on top of each reflector disc. This ensures that the depth values in the centre of the disc are still readable, while the outer reflective ring remains sufficient for the disc detection applied to the IR image.

4. Experiments and Results

4.1. *Multiple Viewpoint Analysis*

$N = 24$ poses are used in this experiment to observe the plate. The sensor in use was the *Asus Xtion*. The resulting hand-eye transform matrix was recorded at each pose,



(a) (b)

Fig. 5. *a*) Depth values unavailable due to high reflectance; *b*) Additional concentric non-reflective disc is added to each reflector disc.

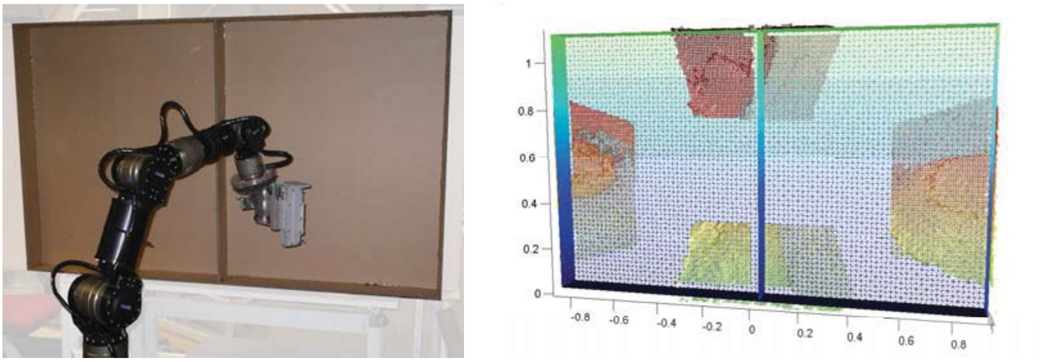
Table 2. Mean and standard deviations for translations/rotations of all sampled transform matrices.

	Mean (mm)	Std. Deviation (mm)
x	-38.4	1.6
y	-102.5	4.4
z	140.3	3.7
	Mean (deg)	Std. Deviation (deg)
roll	-3.78	0.72
pitch	-69.03	0.35
yaw	-3.44	0.69

and a notable distribution in transform matrices in both translation and rotation could be observed (see Table 2).

In order to evaluate the accuracy of the resulting mean hand-eye transform matrix ${}^{e}T_{s,f}$ an attempt at fusing environment meshes was made. A three dimensional structure of known dimensions called a *sidewall* (Fig. 6*a*), was observed from four different viewpoints. The four scans were fused by computing the forward kinematics of the arm in combination with the hand-eye transform matrix and then transforming the point cloud respectively, in order to establish a global map comprised of the four seperate scans (Fig. 6*b*). The accuracy of the fusion was estimated by comparing the fused scans with a template data structure which describes the sidewall, with correct dimensions. Iterative Closest Point (ICP) was then used to determine the RMS error once the point clouds had been registered.

The experiment was performed using two different values for the hand-eye transform matrix. Firstly, the final mean hand-eye calibration matrix ${}^{e}T_{s,f}$ was used, which yielded an RMS error of 1.39e-4. The process was then repeated using one of



(a) (b)

Fig. 6. *a*) Observation of a three dimensional structure with known dimensions; *b*) The fused scanned mesh (red/yellow) overlaid on the template mesh (green/blue).

the outlier ${}^{e}T_{s,i}$ transform matrices within the set of 24 observations. Using this outlier transform matrix, the RMS error was found to be 2.61e-3, an order of magnitude higher.

4.2. *Other experiments*

The approach described in section 3 was also validated by moving the sensor at close range to the calibration plate and verifying that depth values were present at all times. The sensor has a dead-band between approximately 0 to 0.5 metres, as such locations within this range were not considered.

The disc detection improvements were validated by adding various objects which would introduce artifacts into the IR image (Fig. 3*a*). A total of 24 viewpoints were used, and a 95.8% success rate for detection was found, a notable improvement upon the previous approach which yielded a 70.8% success rate.

For testing the fault recovery approach, all known error conditions were artificially introduced during the calibration process, and successful recovery was consistently observed in each case.

5. Conclusions

The improvements to the calibration approach [3] have been successfully verified to quantifiably improve the reliability and accuracy of the IR range camera calibration process. Increased accuracy in this case results in improvement of the performance of the robot during grit-blasting operation, with a lower likelihood of collision with environment obstacles. Although the calibration process involves a number of steps, these steps were automated for ease of use such that execution in a field environment is a straightforward process and can be performed by inexperienced field operators.

Future work will involve testing the approach on IR range cameras with different properties such as a greater field of view and wider range of depth values.

Acknowledgments

This work is supported by the Australian Research Council (ARC) Linkage Grant (ARCLP0776312), the Roads and Maritime Services of New South Wales (RMS), and the University of Technology, Sydney (UTS).

REFERENCES

1. G. Paul, S. Webb, D. K. Liu, and G. Dissanayake, "A robotic system for steel bridge maintenance: Field testing," in *Australasian Conference on Robotics and Automation*, Brisbane, Australia, 2010, pp. 1 – 8.
2. D. Liu, G. Dissanayake, P. B. Manamperi, G. Fang, N. Kirchner, G. Paul, S. Webb, P. Chotiprayanakul, and J. Xie, "A robotic system for steel bridge mainteance: Research challenges and system design," in *Australasian Conference on Robotics and Automation*, Canberra, Australia, 2008.
3. A. W. K. To, G. Paul, D. Rushton-Smith, D. K. Liu, and G. Dissanayake, "Automated and frequent calibration of a robot manipulator-mounted ir range camera for steel bridge maintenance," in *Int. Conf. on Field and Service Robotics*, Matsushima, Miyagi, Japan, 2012, pp. 1 – 14.
4. Y. C. Shiu and S. Ahmad, "Calibration of wrist-mounted robotic sensors by solving homogeneous transform equations of the form ax=xb," *Robotics and Automation, IEEE Transactions on*, vol. 5, pp. 16 – 29, 1989.
5. H. Zhuang, Z. S. Roth, and R. Sudhakar, "Simultaneous robot/world and tool/flange calibration by solving homogeneous transformation equations of the form ax=yb," *Robotics and Automation, IEEE Transactions on*, vol. 10, pp. 549 – 554, 1994.
6. X. Meng and Z. Hu, "A new easy camera calibration technique based on circular points," *Pattern Recognition*, vol. 36, pp. 1155 – 1164, 2003.
7. M. Dinham and G. Fang, "Low cost simultaneous calibration of a stereo vision system and a welding robot," in *Robotics and Biomimetics, IEEE Int. Conf. on*, Tianjin, China, 2010, pp. 1452 – 1456.
8. G. Fang and M. Dinham, "A low cost hand-eye calibration method for arc welding robots," in *Robotics and Biomimetics, Int. Conf. on*, Guilin, China, 2009, pp. 1889 – 1893.
9. Q. Shi, N. Xi, Y. Chen, and W. Sheng, "Registration of point clouds for 3d shape inspection," in *Intelligent Robots and Systems, Int. Conf. on*, Beijing, China, 2006, pp. 235 – 240.
10. S. May, D. Droeschel, S. Fuchs, D. Holz, and A. Nuchter, "Robust 3d-mapping with time-of-flight cameras," in *Intelligent Robots and Systems, Int. Conf. on*, St Louis, Missouri, USA, 2009, pp. 1673 – 1678.
11. C. S. Gatla, R. Lumia, J. Wood, and G. Starr, "Calibrating pan-tilt cameras in robot hand-eye systems using a single point," in *Robotics and Automation, 2007 IEEE Int. Conf. on*, Rome, Italy, 2007, pp. 3186 – 3191.
12. G. R. Arce, "Nonlinear signal processing: A statistical approach," *Wiley:New Jersey*, 2005.

ISRM 2013 notification for paper 45

ISRM 2013 [isrm2013@easychair.org]
Sent: Sunday, June 02, 2013 2:38 AM
To: Andrew To

Dear Andrew To,

It is our pleasure to inform you that the paper:

45 : An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications

has been accepted for presentation at the 3rd IFToMM International Symposium on Robotics and Mechatronics (ISRM 2013) to be held in Singapore on October 2-4, 2013.

Please convey this information and my congratulations to your co-authors, if any.

Each final paper submission requires one regular advanced registration. Acceptance of your paper is made with the understanding that at least one author will attend and also present the paper at the conference. In the case of a no-show from all of the authors, the paper will be removed from the proceedings.

Please revise your manuscript according to reviewers' comments. The reviews are attached to this letter for your reference. When revising your manuscript, please make sure to follow the proper format in order to be included in the proceedings.

The deadline of submission of the camera-ready paper is July 1, 2013. Detailed instructions and the link to the submission site is available on the conference website: http://2013.isrm-iftomm.org

Each submission must be accompanied with a signed Assignment of Copyright; the form is available to download from the submission page of the conference website.

Please take note of the following dates:

June 1 - Opening of registration (including advance registration)
July 1 - Submission of camera-ready papers
July 15 - Deadline of advance registration
August 31 - Advance Program will be available

On behalf of the ISRM 2013 Program and Organising Committees, thank you for your contribution and looking forward to seeing you in Singapore in October.

Sincerely,

Guilin Yang
Program Chair

I-Ming Chen
General Chair

----------------------- REVIEW 1 ---------------------
PAPER: 45
TITLE: An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications

AUTHORS: David Rushton-Smith, Andrew To, Gavin Paul and Dikai Liu

----------- REVIEW -----------
The main contribution of this paper seems to be a technique to calibrate the relative pose of the sensor and the end-effector of the robot such that a reliable scan can be achieved after dismounting and mounting the sensor.

The presentation of the paper is acceptable but the units for the final results (pages 8 and 9) in the experiment section should be given.

----------------------- REVIEW 2 ---------------------
PAPER: 45
TITLE: An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications
AUTHORS: David Rushton-Smith, Andrew To, Gavin Paul and Dikai Liu

----------- REVIEW -----------
This paper presents improvements for the author's old work on hand-eye calibration. The improvements include disc configuration modification, disc detection from IR images using morphological close operation, pose estimation using images captured from different view points, outlier rejection such as checking the number of detect discs.

These improvements have already been considered in many research prototypes and actual systems (for example, Zhengyou Zhang's calibration paper published at TPAMI 2000 shows that the requirement of images captured with multiple view points), and are known to provide more accurate results. Therefore, I do not think that this paper has significant contributions for ISRM publication.

----------------------- REVIEW 3 ---------------------
PAPER: 45
TITLE: An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications
AUTHORS: David Rushton-Smith, Andrew To, Gavin Paul and Dikai Liu

----------- REVIEW -----------
This paper presents a method for calibrating a manipulator-mounted IR camera. Is is stated that this approach is improved in accuracy and reliability.
The improvement is obtained by the use of a proper image processing technique, by the selection of proper camera viewpoints and by a procedure for fault detection recovery.
The image processing technique is a sequence of operations that improve the quality of the image of the discs used by the calibration procedure. The proposed sequence works well for this particular case and does not seem to be possible of generalization.
The selection of proper camera viewpoints is based on an array of predetermined poses using both rotation and translation of the manipulator. This is an exhaustive method and it is not shown that these positions optimize the calibration procedure.
The procedure for fault detection recovery is not more than giving up the current measurement in case of fail and proceed in the next position. There is not a clear contribution in this procedure.
Experimental results show the improvement of the calibration procedure using the proposed method. Clearly the proposed method works well for this arrangement of camera and manipulator but it is not a general calibration procedure that could be applied to other situation and that fact is what limits the contribution of this

work.

------------------------ REVIEW 4 ---------------------
PAPER: 45
TITLE: An Accurate and Reliable Approach to Calibration of a Robot Manipulator-Mounted IR Range Camera for Field Applications
AUTHORS: David Rushton-Smith, Andrew To, Gavin Paul and Dikai Liu

----------- REVIEW -----------
The paper provides a method of hand-eye calibration for bridge maintenance robot. The key part is to get the transformation between the camera frame and the base frame. By using the reflect disk, a sequence of procedures are used to get an accurate transformation. This is not a very new idea in term of the theoretical contribution. However, the paper is clearly presented and results are sounded. A suggestion is that a clear picture of location information about the end effect and IR camera should be provided for readers to have a better view of hand-eye transformation. Another question is what the accuracy of IR sensor particularly in the real environment with dust is.

The 3rd IFTOMM International Symposium on Robotics and Mechatronics

1 – 4 October 2013, Singapore

Program Booklet

ORGANIZERS

IFToMM Technical Committee on Robotics & Mechatronics (IFToMM TC-RM)

Singapore Committee for the Technologies of Machines and Mechanisms (SiCToMM)

IEEE Robotics & Automation Singapore Chapter

School of Mechanical & Aerospace Engineering (MAE), Nanyang Technological University (NTU)

SPONSORS

WELCOME MESSAGE

I-Ming Chen
General Chairman
ISRM 2013

It is a pleasure to welcome everybody to the beautiful garden city and country, Singapore, for the 2013 IFToMM International Symposium on Robotics and Mechatronics (ISRM). This is the third in the series following the previous ones held in Hanoi, Vietnam (2009) and Shanghai, China (2011).

ISRM 2013 is an event organized by the Technical Committee on Robotics and Mechatronics under the International Federation for the Promotion of Mechanism and Machine Science (IFToMM). The aim of this symposium is to promote timely scholarly exchange for the robotics and mechatronics R&D community. The ISRM 2013 proceedings present state-of-the-art research findings in robotics and mechatronics in the 78 articles by authors from 15 countries throughout five continents. Major topics of the papers are in parallel manipulators, bio-inspired robotics, mobile robotics, locomotion and gait planning, sensors and sensing systems, actuators and drive mechanisms, compliant mechanisms, and motion tracking and localization. All papers have been rigorously reviewed by at least two international peer reviewers, and are organized into a 3-day conference with 14 technical sessions held from 2 to 4 October 2013 in Nanyang Technological University, Singapore.

As the trend of 21st century R&D work is moving toward interdisciplinary and socially relevant, ISRM 2013 invited two distinguished plenary speakers, Prof. Yoshihiko Nakamura (University of Tokyo, Japan) and Dr. Ser Yong Lim (Singapore Institute of Manufacturing Technology, Singapore) to share their experiences and perspectives in carrying out robotics and mechatronics R&D for disaster relief, especially the decommissioning and safety of nuclear facilities, as well as for advanced manufacturing, especially ultra-precision manufacturing and highly challenging automation works. Sustainable environmentally safe development and economic growth of the society we live in through manufacturing productivity improvement and improved quality of life are very critical to nation building. Robotics and mechatronics are at the heart of these interdisciplinary and advance society-relevant areas.

The organizers would like to thank members of the International Program Committee, the Scientific Committee of ISRM and the Local Organizing Committee for their efforts in reviewing the submitted articles, and the authors in addressing the comments and suggestions of the reviewers in their final submissions. The financial support received from IFToMM for the Young Delegation Program (YDP) is also acknowledged. The technical support received from Singapore Committee for Promotion of Mechanism and Machine Science (SiCToMM), the School of Mechanical and Aerospace Engineering, Robotics Research Center (RRC), Intelligent Systems Center (Intellisys) in Nanyang Technological University, Singapore Institute of Manufacturing Technology (SIMTech), Singapore University of Technology and Design, and National University of Singapore are all acknowledged. Strong support received from Beijing University of Aeronautics and Astronautics, China is also much appreciated.

ORGANIZING COMMITTEE

General Chair	**I-Ming Chen**
	Nanyang Technological University, Singapore
General Co-Chair	**Marcelo H. Ang, Jr**
	National University Singapore
Program Chair	**Guilin Yang**
	SIMTech, Singapore
Program Co-Chair	**Domenico Campolo**
	Nanyang Technological University, Singapore
Organized Sessions Chair	**Wei Lin**
	SIMTech, Singapore
Publicity Chairs	**Yan Chen**
	Tianjin University, China
	Wenjie Chen
	SIMTech, Singapore
Publication Chair	**Kin Huat Low**
	Nanyang Technological University, Singapore
Finance Chair	**Song Huat Yeo**
	Nanyang Technological University, Singapore
Local Arrangement Chairs	**Mustafa S Kurbanhusen**
	SIMTech, Singapore
	Shaohui Foong
	Singapore University of Technology & Design, Singapore
	Soh Gim Song
	Singapore University of Technology & Design, Singapore
Webmaster	**Albert Causo**
	Nanyang Technological University, Singapore
Secretary	**Noraidillah Bte Mohamed Ali**
	Nanyang Technological University, Singapore

INTERNATIONAL SCIENTIFIC COMMITTEE

I-Ming Chen, Singapore (Co-Chair)
Bodo Heimann, Germany (Co-Chair)
Marco Ceccarelli, Italy
Shuo-Hung Chang, China-Taipei
Nguyen Phong Dien, Vietnam
Feng Gao, China-Beijing
Yukio Takeda, Japan
Min-June Tsai, China-Taipei
Teresa Zielinska, Poland
Said Zeghloul, France
Nguyen Van Khang, Vietnam
Manfred Hiller, Germany
Qiang Huang, China-Beijing
Lotfi Rondhame, Tunisia

ACKNOWLEDGEMENT

PROGRAMME COMMITTEE MEMBERS

Albert Causo
Albertus Adiwahono
Anthony Wong
Arun Dayal Udai
Ashitava Ghosal
Ben Jonker
Bingbing Li
Bingbing Liu
Bodo Heimann
Chao-Yang Song
Charles Ng
Cheng-Chen Yang
Chenming Zhou
Chin-Yin Chen
Chow Yin Lai
Chun Chieh Wang
Dikai Liu
Eduardo Castaneda
Foong Shaohui
Fugui Xie
Ganesh Krishnasamy
Gang Chen
Genadijus Kulvietis
Gim Song Soh
Giuseppe Carbone
Grigore Gogu
Haoyong Yu
Houssem Saafi
Huaizhu Li
Huy Hoang Pham
Huy Hoang Pham
I-Ming Chen
James Trevelyan
Jinsung Kwon
Jiri Krejsa
Jun Okamoto
Kang Li
Karl Gotlih
Liandong Zhang
Liang Yan
Liang Zhang
Lily Liu
Lin Wei
Lotfi Romdhane
Majid Koul
Marco Ceccarelli
Mario Acevedo
Massimo Sorli
Miguel Angel Naya Villaverde
Min June Tsai
Mustafa Kurbanhusen
Nobuyuki Iwatsuki
Oscar Altuzarra
Oswaldo Horikawa
Oussama Khatib
Pengfei Wu
Pey Yuen Tao
Pinghong Wu
Pranav Bhounsule
Qian Zhao
Qiang Huang
Qilong Yuan
Ramutis Bansevicius
Riby Abhraham Boby
Subir Kumar Saha
Said Zeghloul
Saj Manoj
Samir Menon
Sandipan Bandyopadhyay
Shanbao Cheng
Shu-Yun Chung
Shuo Hung Chan
Stefan Havlik Tadeusz Uhl
Yu Zheng
Yukio Takeda
Zhengneng Yin
Zhiqiang Bi Takaaki Shiratori
Tarcisio Cohelo
Tat Joo Daniel Teo
Teresa Zielinska
Tjahjowidodo Tegoeh
Truong Giang Vo
U-Xuan Tan
Umashankar Nagajaran
Wei Sin Ang
Weider Chung
Weiwei Huang
Wenjie Chen
Wenqiang Wu
Xin-Jun Liu
Xiyang Yeh
Yan Chen
Yan Jin
Yangmin Li
Yisheng Guan

CONFERENCE VENUE

Nanyang Technological University (NTU)
50 Nanyang Avenue
SINGAPORE 639798

SECRETARIAT DESK

(for the duration of the conference only)
Address: **LT3 (NS4-02-32)**
Block NS4, Level 2, Room No 32
Nanyang Technological University
50 Nanyang Avenue
SINGAPORE 639798
Contact Person: Albert Causo
+65 90873849 (mobile)

Secretariat Desk Operating Hours:

Tuesday, 1 October:	14:30 – 19:00
Wednesday, 2 October:	08:30 – 17:30
Thursday, 3 October:	08:30 – 14:00
Friday, 4 October:	08:30 – 17:30

REGISTRATION

Registration is at the Secretariat Desk outside LT3 (NS4-02-32).

Delegates may collect their conference materials at the registration desk during these hours. Name badges are provided and must be worn at the conference are.

WIFI INTERNET

Participants are free to use the NTU wireless network within the campus.

WIRELESS NETWORK: **NTUWL**
DOMAIN: **ASSOC**

Please get your wifi account at the Secretariat desk. Each delegate will be issued an account valid for the duration of the conference.

TOURS & SOCIALS

Campus Tour
Date: 1 October, Tuesday
Time: 15:00-15:45 (Batch 1), 16:00-16:45 (Batch 2)
Venue: Around NTU Campus
Assembly Point: LT3

Welcome Reception
Date: 1 October, Tuesday
Time: 17:00-19:00
Venue: LT3
Assembly Point: LT3 at 16:50

Cultural Tour of Singapore (City Tour)
Date: 3 October, Thursday
Time: 14:00-18:30
Venue: Chinatown, Little India, Merlion Park, Esplanade, Gardens By The Bay
Assembly Point: LT3 at 13:45

Banquet
Date: 3 October, Thursday
Time: 19:00-21:00
Venue: The Seafood International @ East Coast
Assembly Point: Right after the Cultural Tour

Technical Tour
Date: 4 October, Friday
Time: 15:10-17:30
Venue: The Singapore Institute of Manufacturing Technology (SIMTech)
Robotics Research Centre (RRC)
Assembly Point: LT3 at 15:00

Farewell Party
Date: 4 October, Friday
Time: 17:30-19:30
Venue: TBA
Assembly Point: LT3 at 17:30

SHUTTLE BUS FROM PARK AVENUE ROCHESTER HOTEL TO NTU

- Available on mornings of Oct 2, 3, and 4.
- Departure time from hotel will be available at the hotel, website, and the Secretariat Desk.

PROGRAMME-AT-A-GLANCE

1 Oct 2013 (Tuesday)	**14:30 - onwards**	**Registration** (LT3)		
	15:00 - 15:45	**Campus Tour**		
	16:00 - 16:45	**Campus Tour**		
	17:00 - 19:00	**Welcome Reception** (LT3)		

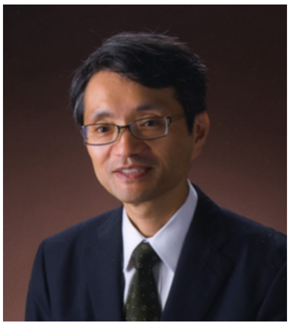
2 Oct 2013 (Wednesday)	**08:45 - 09:00**	**Opening Ceremony** (LT3)	
	09:00 - 10:00	**Keynote Speech by Prof. Yoshihiko Nakamura** (LT3)	
	10:00 - 10:20	*Tea Break*	
	10:20 - 12:20	**WeA1** (LT9)	**WeA2** (LT10)
	12:20 - 13:20	*Lunch*	
	13:20 - 15:20	**WeB1** (LT9)	**WeB2** (LT10)
	15:20 - 15:40	*Tea Break*	
	15:40 - 17:40	**WeC1** (LT9)	**WeC2** (LT10)

3 Oct 2013 (Thursday)	**09:00 - 10:40**	**ThA1** (LT9)	**ThA2** (LT10)
	10:40 - 11:00	*Tea Break*	
	11:00 - 12:40	**ThB1** (LT9)	**ThB2** (LT10)
	12:40 - 14:00	*Lunch*	
	14:00 - 18:30	**Cultural Tour of Singapore (City Tour)**	
	19:00 - 21:00	**Banquet** (The Seafood International @ East Coast)	

4 Oct 2013 (Friday)	**09:00 - 10:00**	**Keynote Speech by Dr. Lim Ser Yong** (LT3)		
	10:00 - 10:20	*Tea Break*		
	10:20 - 12:20	**FrA1** (LT9)	**FrA2** (LT10)	**Industrial Forum I** (LT3)
	12:20 - 13:30	*Lunch*		
	13:30 - 15:10	**FrB1** (LT9)	**FrB2** (LT10)	**Industrial Forum II** (LT3)
	15:10 - 17:30	**Technical Tours**		
	17:30 - 19:30	**Farewell Party**		

Robotics and Community for Decommissioning and Safety of Nuclear Facilities

2 Oct 2013 (Wednesday), 09:00 - 10:00 at LT3



Professor Yoshihiko Nakamura
Department of Mechano-Informatics, University of Tokyo

Abstract

The technologies of robotics and automation are more demanded than ever for nuclear power plants and the other nuclear facilities, after the accidents at TEPCO's Fukushima 1st Nuclear Power Plant following the earthquake and tsunami on March 11th, 2011. Technical Committee on Robotics and Automation in Nuclear Facilities was founded as a TC of IEEE Robotics and Automation Society. This talk will cover the specific technical issues related to robotics for decommissioning TEPCO's Fukushima Daiichi Nuclear Power Plant. The future possibility of robotics solutions in particular with the use of humanoid robots are also discussed.

Biography

Yoshihiko Nakamura received Doctor of Engineering Degree from Kyoto University in 1985. He was Assistant Professor of Kyoto University, from 1982 to 1987, and then Assistant and Associate Professor of University of California, Santa Barbara from 1987 to 1991. Since 1991, he has been with University of Tokyo, Japan, and is currently Professor at Department of Mechano-Informatics. Humanoid robotics, cognitive robotics, neuro musculoskeletal human modeling, biomedical systems, and their computational algorithms are his current fields of research. He is Fellow of Japan Society of Mechanical Engineers, Fellow of Robotics Society of Japan, Fellow of IEEE, and Fellow of World Academy of Arts and Science. Dr. Nakamura currently (2012-2015) serves as President of International Federation for the Promotion of Mechanism and Machine Science (IFToMM). He is Foreign Member of Academy of Engineering Science of Serbia, and TUM Distinguished Affiliated Professor of Technische Universität München. Dr. Nakamura is co-chairing IEEE-RAS Technical Committee on Robotics and Automation in Nuclear Facilities.

KEYNOTE SPEAKER II

Enhance Competitiveness through R&D in Manufacturing Technologies

4 Oct 2013 (Friday), 09:00 - 10:00 at LT3

Dr. Ser Yong Lim
Executive Director, Singapore Institute of Manufacturing Technology,
*Agency for Science, Technology and Research (A*STAR), Singapore*

Abstract

Manufacturing is an important driver of Singapore's economy, contributing to more than 20% of its GDP and employing more than 500,000 people. Singapore Institute of Manufacturing Technology (SIMTech), a research institute under the Agency of Science, Technology and Research (A*STAR) of Singapore, was established in 1993 as part of the national initiative to restructure Singapore into a knowledge-based and technology-driven economy. With its mission to develop high value manufacturing technologies to help the manufacturing industry move up the value chain, SIMTech has made great strides in the R&D of a wide spectrum of technologies for the manufacturing industry. This talk aims to give an overview of SIMTech R&D focus and describe the working models with the manufacturing companies in Singapore. In addition, the talk will give some examples of how R&D contributes to the competitiveness and productivity improvement of the manufacturing industry and present several research programmes that aim to transform future manufacturing industries in Singapore.

Biography

Dr. Ser Yong Lim is the Executive Director and Senior Scientist of the Singapore Institute of Manufacturing Technology (SIMTech), a research institute under the Agency for Science, Technology and Research (A*STAR) of Singapore. Dr. Lim leads the institute in the research and development of technologies in manufacturing processes, manufacturing automation, and manufacturing systems to support the manufacturing industry in Singapore. Under his leadership, SIMTech has collaborated with many research organisations and universities around the world. With more than 350 research scientists and engineers, SIMTech works with manufacturing companies in Aerospace, Automotive, MedTech, Precision Engineering, Electronics, Marine, Oil and Gas, and Logistics industry. Dr. Lim received his B.Eng. (1^{st} Class Honours) from the National University of Singapore in 1984, and his Ph.D. from Clemson University, USA, in 1994. He has worked in the industry in Singapore and the US. Currently, Dr Lim is also an Adjunct Associate Professor with the National University of Singapore. His personal research interests are in Dynamics of Motion, Nonlinear Control of Robotic Manipulators, Ultra-precision Motion Systems, Automation, and Real-time Systems.

Time	WeA1: Parallel Manipulators I Session Chair: Yan Jin Venue: LT9		WeA2: Sensing Session Chair: Gim Song Soh Venue: LT10	
10:20 - 10:40	WeA1.1	**DESIGN AND SIMULATION OF CASSINO HEXAPOD II** DANIELE CAFOLLA, FRANCO TEDESCHI AND GIUSEPPE CARBONE	WeA2.1	**IMPROVE EFFICIENCY OF ULTRASONIC TRANSDUCER BY WAVE REFLECTION METHOD** CHIH-CHUNG SU, CHI-NUNG HUANG, YU-JEN CHEN AND SHUO-HUNG CHANG
10:40 - 11:00	WeA1.2	**LESS-SINGULAR ASSEMBLY-MODE FOR 3-RRR SPHERICAL PARALLEL MANIPULATOR** HOUSSEM SAAFI, MED AMINE LARIBI AND SAID ZEGHLOUL	WeA2.2	**DESIGN OF TACTILE SENSOR ARRAY FOR ELECTRIC GRIPPER JAWS AND OBJECT RECOGNITION** WEN-CHING KO, JUI-YIAO SU, YAN-CHEN LIU, CHANG-HO LIOU AND JWU-SHENG HU
11:00 - 11:20	WeA1.3	**STRUCTURAL-PARAMETRIC SYNTHESIS OF THE PLANAR PARALLEL MANIPULATOR WITH TWO END-EFFECTORS** ZHUMADIL BAIGUNCHEKOV, MYRZABAY IZMAMBETOV AND NURLAN BAIGUNCHEKOV	WeA2.3	**DEVELOPMENT OF A SENSOR-BASED GLOVE DEVICE FOR EXTRACTING HUMAN FINGER MOTION DATA USED IN THE DESIGN OF MINIMALLY ACTUATED MECHANICAL FINGERS** NINA P. ROBSON, SHRAMANA GHOSH AND GIM SONG SOH
11:20 - 11:40	WeA1.4	**A STYLIZED GENERIC METHOD FOR FORWARD POSITION ANALYSIS OF 3-SPS TYPE SPHERICAL PARALLEL MECHANISM BASED ON COUPLING DEGREE ANALYSIS** HONGBO YIN, HUIPING SHEN AND TINGLI YANG	WeA2.4	**LEARNING CORIOLIS-TYPE OF FORCE FIELDS WITHOUT ROBOTS** PAOLO TOMMASINO, YEOW NEO ENG, GIA HOANG PHAN, FERDINAN WIDJAJA, KUMUDU GAMAGE AND DOMENICO CAMPOLO
11:40 - 12:00	WeA1.5	**AUTOMATED AIRCRAFT ASSEMBLY WITH PARALLEL KINEMATIC MACHINE** YAN JIN, PETER MCTOAL, COLM HIGGINS, HARVEY BROOKES AND MARK SUMMARS	WeA2.5	**UNCALIBRATED VISION-BASED CONTROL FOR OPTICAL MANIPULATION OF MICROSCOPIC PARTICLES** XIANG LI AND CHIEN CHERN CHEAH
12:00 - 12:20	WeA1.6	**A NOVEL PARALLEL ROBOT WITH SCARA MOTIONS AND ITS KINEMATIC ISSUES** FUGUI XIE, XIN-JUN LIU AND YANHUA ZHOU	WeA2.6	**AMBULATORY MEASUREMENT OF SHOULDER KINEMATICS USING INERTIAL MEASUREMENT UNITS AND SHOULDER RHYTHM MODEL** WEI SIN ANG, I-MING CHEN AND QI LONG YUAN

PRESENTATION LISTING: Wednesday, 2 October 2013

Time	WeB1: Parallel Manipulators II Session Chair: Yukio Takeda Session Co-chair: Chao Chen Venue: LT9		WeB2: Actuators and Drives Session Chair: Liang Yan Session Co-Chair: Pham Hong Phuc Venue: LT10	
13:20 - 13:40	WeB1.1	**SYNTHESIS OF ADJUSTABLE PLANAR AND SPHERICAL FOUR-LINK MECHANISMS FOR APPROXIMATE MULTI-PATH GENERATION** PRASAD VILAS CHANEKAR AND ASHITAVA GHOSAL	WeB2.1	**DYNAMIC SYNTHESIS OF MANIPULATOR ADAPTIVE DRIVE** KONSTANTIN IVANOV, GAKHIP UALIEV AND BAURJAN TULTAEV
13:40 - 14:00	WeB1.2	**NOVEL LINKAGE WITH REMOTE CENTER OF MOTION** CHAO CHEN AND MAX PAMIETA	WeB2.2	**MULTI-SISO CONTROL TO REGULATE CONSTANT POWER AND MITIGATE DRIVE-TRAIN LOAD IN WIND TURBINE** LIZA WAN YUAN CHUA, IRVING PAUL GIRSANG AND JASPREET SINGH DHUPIA
14:00 - 14:20	WeB1.3	**PATH PLANNING OF THE 3-RPR USING GLOBAL WORKSPACE ROADMAPS** WESLEY AU, CHAO CHEN AND HOAM CHUNG	WeB2.3	**DESIGN AND FABRICATION OF A MICRO CAM MECHANISM BASED ON ELECTROSTATIC COMB-DRIVE ACTUATORS** PHUC PHAM HONG, TOAN DINH KHAC, KHOA NGUYEN TUAN AND LAM DANG BAO
14:20 - 14:40	WeB1.4	**KINEMATIC AND DYNAMIC SIMULATION OF A RECONFIGURABLE PARALLEL ROBOT** DOINA PISLA, DRAGOS COCOREAN, CALIN VAIDA, BELA GYURKA, ADRIAN PISLA AND NICOLAE PLITEA	WeB2.4	**DYNAMIC ANALYSIS OF PLANETARY GEAR INCREASER USING A VARYING STIFFNESS DISCRETE MODEL** KUO JAO HUANG AND SUNG WEN CHEN
14:40 - 15:00	WeB1.5	**ON THE SLIDING MODE CONTROL OF REDUNDANT PARALLEL ROBOTS USING NEURAL NETWORKS** NGUYEN VAN KHANG AND LUONG ANH TUAN	WeB2.5	**A CURRENT-SENSING BASED CONTROLLER OF BRUSHED DC MOTORS FOR ROBOTIC APPLICATIONS** ARUN UDAI AND SUBIR SAHA
15:00 - 15:20	WeB1.6	**COMPLIANCE ANALYSIS OF 3-RPSR PARALLEL MECHANISM FOR MOVABLE-DIE DRIVE MECHANISM OF PIPE BENDER** YUKIO TAKEDA, SHOHEI KAWASUMI, DAISUKE MATSUURA AND EDUARDO CASTILLO-CASTANEDA	WeB2.6	**MAGNETIC FIELD ANALYSIS OF ROTARY MACHINES WITH DOUBLE-LAYERED HALBACH ARRAY** LIANG YAN

Time	WeC1: Bio-inspired Robotics Session Chair: Wenbin Lim Venue: LT9		WeC2: Mobile Robotics I Session Chair: Dikai Liu Session Co-chair: Bingbing Li Venue: LT10	
15:40 - 16:00	WeC1.1	**BIO-INSPIRED MECHANICAL DESIGN OF WALKING HEXAPOD ROBOT FOR TERRAIN NEGOTIATION** DONG LIU, WEIHAI CHEN, ZHONGCAI PEI AND JIANHUA WANG	WeC2.1	**TOWARDS AN ACTIVE SPINE FOR MOBILE ROBOTS** DANIEL KUEHN, FRANK BEINERSDORF, MARC SIMNOFSKE, FELIX BERNHARD AND FRANK KIRCHNER
16:00 - 16:20	WeC1.2	**SLIDING FRICTION MECHANISM THAT MIMICS THE SLIDING FILAMENT MODEL OF SKELETAL MUSCLE** FRANCIS NICKOLS	WeC2.2	**ROBUST ADAPTIVE CONTROL OF AN OMNIDIRECTIONAL MOBILE ROBOT USING OMNIDIRECTIONAL VISION SENSOR** YC YANG, CC CHENG AND CY CHEN
16:20 - 16:40	WeC1.3	**AN ACTIVE JOINT DRIVEN BY MULTIPLE ACTUATORS WITH HYDRAULIC SKELETON MECHANISM MADE OF FLEXIBLE BAGS** HITOSHI KIMURA, TAKUYA MATSUZAKI, MOKUTARO KATAOKA AND NORIO INOU	WeC2.3	**AN ACCURATE AND RELIABLE APPROACH TO CALIBRATION OF A ROBOT MANIPULATOR-MOUNTED IR RANGE CAMERA FOR FIELD APPLICATIONS** DAVID RUSHTON-SMITH, ANDREW TO, GAVIN PAUL AND DIKAI LIU
16:40 - 17:00	WeC1.4	**INVERSE KINEMATICS OF A WIRE-ACTUATED CONSTANT-CURVATURE FLEXURAL MECHANISM** CHIN-HSING KUO AND WANG-NIN LIAN	WeC2.4	**MOVING OBSTACLE AVOIDANCE VIA TIME-VARYING COST MAP** SCOTT PENDLETON, XIAOTONG SHEN AND MARCELO ANG
17:00 - 17:20	WeC1.5	**DISPLACEMENT AND TENSION ANALYSIS FOR CABLE-DRIVEN MANIPULATORS** WENBIN LIM, SONG HUAT YEO, GUILIN YANG AND YAN XIN TAN	WeC2.5	**MOTIVATED LEARNING EMBODIED IMPLEMENTATION IN AUTONOMOUS SYSTEMS - A CASE STUDY IN NAO ROBOT** LILI LIU, BINGBING LI, CHUNYANG SUN AND I-MING CHEN
17:20 - 17:40	WeC1.6	**DYNAMIC FRICTION MODEL FOR TENDON SHEATH ACTUATED SURGICAL ROBOTS: MODELLING AND STABILITY ANALYSIS** THANH NHO DO, TEGOEH TJAHJOWIDODO, MICHAEL WAI SHING LAU AND SOO JAY PHEE	WeC2.6	**DEXTERITY ANALYSIS FOR QUADRUPED ROBOTS BASED ON THE IMPROVED SERVICE SPHERE** XILUN DING AND HAO CHEN

PRESENTATION LISTING: Thursday, 3 October 2013

Time	ThA1: Compliant Mechanisms Session Chair: Weihai Chen Session Co-chair: Xu Pei Venue: LT9		ThA2: Mobile Robotics II Session Chair: Martim Brandao Session Co-chair: Xiaolei Han Venue: LT10	
9:00 - 9:20	**ThA1.1**	**MAKE A COMPLIANT MECHANISM WITH A LOW-COST DESKTOP 3D PRINTER** XU PEI, I-MING CHEN AND QILONG YUAN	**ThA2.1**	**ARX-FCM METHOD FOR STEERING SYSTEM FAULT DIAGNOSIS OF A HEAVY CONSTRUCTION VEHICLE** LIMAN YANG, MING ZHANG, KOK-MENG LEE AND YUNHUA LI
9:20 - 9:40	**ThA1.2**	**DESIGN AND MODELING OF A LARGE DISPLACEMENT FLEXURE-BASED PARALLEL MICRO-POSITIONING STAGE** WEIHAI CHEN, JIANLIANG QU, JIANBIN ZHANG AND YAN JIN	**ThA2.2**	**MULTI-INFORMATION PARTICLE SWARM OPTIMIZATION FOR WEAPON TARGET ASSIGNMENT OF MULTIPLE KILL VEHICLE** YUNTAO HUANG AND LIMAN YANG
9:40 - 10:00	**ThA1.3**	**DESIGN OF A COMPLIANT DELTA ROBOT FOR FLEXIBLE ASSEMBLY** JWU-SHENG HU, CHENG-HUA WU, YI-JENG TSAI, WEI-HAN WANG AND SHOU-WEI CHI	**ThA2.3**	**ACTIVE GAZE STRATEGY FOR REDUCING MAP UNCERTAINTY ALONG A PATH** MARTIM BRANDAO, KENJI HASHIMOTO AND ATSUO TAKANISHI
10:00 - 10:20	**ThA1.4**	**PRECISION ANALYSIS AND VERIFICATION OF A FIVE-BAR LINKAGE WITH COMPLIANT JOINTS** CHING-SHIN LIN AND JYH-JONE LEE	**ThA2.4**	**LOW BIT RATE SPEECH CODING FOR RESCUE ROBOTICS** XIAOLEI HAN AND FENG GAO
10:20 - 10:40	**ThA1.5**	**AN ACTIVE HANDHELD INSTRUMENT AIDED WITH VIRTUAL FIXTURES FOR REAL-TIME MICROMANIPULATION USING FUSION OF VISION AND INERTIAL SENSING** YAN NAING AYE, SU ZHAO, ZENAN WANG AND WEI TECH ANG	**ThA2.5**	**STATISTICAL ATLAS BASED 3D-2D REGISTRATION** KEYU WU AND HONGLIANG REN

Time	ThB1: Modeling and Analysis Session Chair: Yuo Tern Tsai Venue: LT9		ThB2: Locomotion and Gait Planning Session Chair: Kin Huat Low Session Co-chair: Trung Kien Dao Venue: LT10	
11:00 - 11:20	**ThB1.1**	**A STUDY OF RELIABILITY OPTIMIZATION DESIGN FOR ROBOTS BASED ON FINITE ELEMENT ANALYSIS** YT TSAI AND KH LIN	**ThB2.1**	**A HUMAN GAIT MODEL USING GRAPH-THEORETIC METHOD** TRUNG KIEN DAO AND VAN HIEP DAO
11:20 - 11:40	**ThB1.2**	**DESIGN OF A 4-LINK PLANAR STATICALLY BALANCED SERIAL MANIPULATOR WITH CHANGEABLE PAYLOAD** HUAN-HAO CHANG AND DAR-ZEN CHEN	**ThB2.2**	**NEURAL PATTERN GENERATION AND KINEMATICS CALCULATION FOR A HEXAPOD ROBOT'S ADAPTIVE LOCOMOTION CONTROL** GUANJIAO REN, WEIHAI CHEN AND JIANHUA WANG
11:40 - 12:00	**ThB1.3**	**ACCELERATION AND NONLINEAR OSCILLATIONS OF PARALLEL SPHERICAL MECHANISM** SERGEY KHEYLO, VICTOR GLAZUNOV AND THANH NGUYEN MINH	**ThB2.3**	**TROT GAIT DESIGN FOR BABY ELEPHANT ROBOT WITH SERIES CPG MODEL** JIAQI ZHANG AND FENG GAO
12:00 - 12:20	**ThB1.4**	**A COMPARATIVE STUDY ON THE CONPUTATIONAL EFFICIENCY OF SOME NUMERICAL METHODS FOR SOLVING THE INVERSE KINEMATICS OF REDUNDANT ROBOTS** NGUYEN VAN KHANG, NGUYEN PHONG DIEN AND LUONG ANH TUAN	**ThB2.4**	**EXPERIMENTAL INVESTIGATION ON MANEUVERABILITY OF A BIONIC FISH PROPELLED BY OSCILLATING PAIRED PECTORAL FINS** YEURI CAI, SHUSHENG BI AND K. H. LOW
12:20 - 12:40	**ThB1.5**	**SYNTHESIS OF MANIPULATORS THAT CAN REACH MULTIPLE SPECIFIED ISOTROPIC POSITIONS** K. Y. TSAI AND P. J. LIN	**ThB2.5**	**GAIT ANALYSIS AND MODELING OF ROBOTIC ORTHOSIS WITH BALANCE STABILIZER** LEI LI, K. H. HOON AND K. H. LOW

PRESENTATION LISTING: Friday, 4 October 2013

Time	FrA1: Mechanisms and Mechatronics Devices Session Chair: Yan Chen Session Co-chair: Massimo Sorli Venue: LT9		FrA2: Advanced Robotics Session Chair: Qilong Yuan Venue: LT10	
10:20 - 10:40	FrA1.1	**RECONFIGURATION IN LINKAGES BY VARIABLE ALLOCATION OF JOINT POSITIONS: A MODULAR DESIGN APPROACH** NICOLAS ROJAS, RAJESH ELARA MOHAN AND RICARDO SOSA	FrA2.1	**MODELING AND FORCE ANALYSIS OF A TASK-ORIENTED HAND-FINGERS REHABILITATION DEVICE FOR ROBOTICS THERAPY** YUNYUN HUANG AND K. H. LOW
10:40 - 11:00	FrA1.2	**BIFURCATION BEHAVIOR OF THE LINE-SYMMETRIC BRICARD LINKAGE WITHOUT OFFSETS** CHAOYANG SONG, YAN CHEN AND I-MING CHEN	FrA2.2	**DEVELOPMENT OF AN INTERACTIVE VIRTUAL SYSTEM FOR TREATMENT OF SELECTIVE MUTISM** TAN ANH KHOA PHAM AND I-MING CHEN
11:00 - 11:20	FrA1.3	**OPTIMIZATION OF REALIZATION OF STATIC BALANCING FOR AN ANTHROPOMORPHIC ROBOT** GIUSEPPE QUAGLIA AND ZHE YIN	FrA2.3	**CONTROL DESIGN OF HAPTIC DEVICE FOR MEDICAL APPLICATION** ABDELBADIÂ CHAKER, MED AMINE LARIBI, SAID ZEGHLOUL AND LOTFI ROMDHANE
11:20 - 11:40	FrA1.4	**DYNAMIC VIBRATION OF CLASS IV MECHANISM** SKANDERBEK JOLDASBEKOV AND YERBOL TEMIRBEKOV, A.A. JOMARTOV	FrA2.4	**DESIGN AND ADMITTANCE CONTROL FOR A HUMANOID MANIPULATOR TO ADAPT TO ENVIRONMENT** GAN MA, QIANG HUANG AND ZHANGGUO YU
11:40 - 12:00	FrA1.5	**ISWEC (INERTIAL SEA WAVE ENERGY CONVERTER): MODELING, CONTROL AND PRODUCTIVITY ANALYSIS** ERMANNO GIORCELLI, GIULIANA MATTIAZZO, MATTIA RAFFERO AND MASSIMO SORLI	FrA2.5	**A DESIGN OF NOVEL MANIPULATOR USING DISTRIBUTED ACTUATION MECHANISM** SUNG-HWAN KIM, KYUNG-SOO KIM AND SOOHYUN KIM
12:00 - 12:20	FrA1.6	**STUDY OF THE CONFIGURATION SPACE OF A MECHANISM FOR A THRUST VECTORING NOZZLE** STEFANO PASTORELLI, GIOVANNI JACAZIO AND MASSIMO SORLI	FrA2.6	**OPTIMAL WORKPLACEMENT FOR ROBOTIC FRICTION STIR WELDING TASK** ACHIN JAIN, JINNA QIN AND GABRIEL ABBA

Time	FrB1: Calibration Session Chair: Hongliang Ren Venue: LT9		FrB2: Motion Tracking and Localization Session Chair: Hong Luo Session Co-Chair: Albert Causo Venue: LT10	
13:30 - 13:50	FrB1.1	**POSE ESTIMATION OF A SIX DEGREES OF FREEDOM PIPE-BENDER USING A 3D-VISUAL MEASUREMENT SYSTEM OF HIGH ACCURACY** EDUARDO CASTILLO-CASTANEDA, YUKIO TAKEDA, SHOHEI KAWASUMI AND DAISUKE MATSUURA	FrB2.1	**WORKPIECE RE-LOCALIZATION FOR AUTOMATIC ROBOT PATH CORRECTION** HONG LUO, TECK CHEW NG AND GUILIN YANG
13:50 - 14:10	FrB1.2	**AUTOMATIC CALIBRATION OF A SURGICAL GUIDANCE ROBOT USING A 3D OPTICAL LOCATOR** MING JUNE TSAI, CHUN-LIN. CHEN, HONG-WEN LEE AND JIA-HONG. CHAO	FrB2.2	**A TRACKING METHOD USING ACTIVE UNIAXIAL SENSOR AND VARIABLE STEP SIZE SEARCHING STRATEGY** SHUANG SONG AND HONGLIANG REN
14:10 - 14:30	FrB1.3	**GEOMETRIC MODEL IDENTIFICATION OF A SERIAL ROBOT** RAJEEVLOCHANA G. CHITTAWADIGI, ABDULLAH AAMIR HAYAT AND SUBIR KUMAR SAHA	FrB2.3	**IMAGE FUSION AT PIXEL LEVEL OF THERMAL AND OPTICAL IMAGES FOR MOTION DETECTION** PATCHARANAN SRITANAUTHAIKORN AND NITIN AFZULPURKAR
14:30 - 14:50	FrB1.4	**TWIST-LOCK POSE ESTIMATION AND GRASPING BASED ON CAD MODEL** LIANDONG ZHANG, CHANGJIU ZHOU, XINYU HAN, SHUANG MA AND RONGHUA LI	FrB2.4	**FULL-BODY MOTION AND VELOCITY TRACKING BASED ON CONTACTS AND BODY KINEMATICS: A KENDO DEMONSTRATION** QILONG YUAN, I-MING CHEN, AND ALBERT CAUSO
14:50 - 15:10	FrB1.5	**REFORMULATION OF THE LOCAL POE FORMULA FOR ROBOT KINEMATIC CALIBRATION** GENLIANG CHEN, HAO WANG AND ZHONGQIN LIN	FrB2.5	**RESEARCH ON THE SWINGING DRIVING MODE BASED ON SLOPING UNIVERSAL WHEELS** XU PEI, SICHENG YANG, I-MING CHEN AND QILONG YUAN

INDUSTRIAL FORUM PROGRAM

DATE: 4 October 2013, Friday

VENUE: Lecture Theatre 3 (LT3), Nanyang Technological University

09:00 - 10:00	ISRM Keynote Speech: Enhancing Competitiveness through R&D in Manufacturing Technologies	Dr. Ser Yong Lim *Executive Director, SIMTech*
10:00 - 10:20	***Tea Break***	
10:20 - 10:25	Opening Remarks	Prof. I-Ming Chen (NTU) *ISRM General Chairman*
10:25 - 10:40	Introduction of A*STAR Industrial Robotics Program	Prof. Marcelo Ang (NUS) *Program Manager*
10:40 - 10:50	Interface for human-robot interaction	Dr. Haizhou Li (I2R)
10:50 - 11:00	Distributed sensing and perception	Prof. Sam Ge (NUS)
11:00 - 11:10	Manipulation & planning	Prof. Kin Huat Low (NTU)
11:10 - 11:30	Robotic Welding	Dr. Wei Lin (SIMTech)
11:30 - 12:20	**Panel Discussion I** (Industrial Robotics Technology & Applications) *Chairman: Prof. Marcelo Ang*	
12:20 - 13:30	***Lunch***	
13:30 - 13:40	Control of dynamic interaction between motion and force during contact	Prof. Marcelo Ang (NUS)
13:40 - 13:50	Adaptation: Task-oriented agile workcell	Prof. I-Ming Chen (NTU)
13:50 - 14:00	Robotic Finishing	Dr. Guilin Yang (SIMTech)
14:00 - 14:10	Robot application development and operating environment (RADOE)	Prof. Marcelo Ang (NUS)
14:10 - 14:20	Talk by Industrial Speaker	Mr. Wee Kwong Na (ST Engineering)
14:20 - 15:10	**Panel Discussion II** (Industrial Robotics Technology & Applications) *Chairman: Prof. Marcelo Ang*	
15:10 - 17:30	**Technical Tour:** NTU Robotics Research Center and SIMTech	
END		

Shuttle Bus from Park Avenue Rochester Hotel to NTU

- Available on the morning of October 2, 3 and 4. Departure time from hotel will be available at the hotel, website, and the Secretariat Desk

Bus Stops inside NTU nearest to conference rooms:

a) Lee Wee Nam Library (Bus 179)
b) Opposite Lee Wee Nam Library (Bus 199)
c) Administration Building (Taxi or Campus Rider Shuttle Bus)

Option 1: TAXI

- It costs around SGD 40 to SGD 50 from airport to NTU, and around SGD 25 - SGD 35 from city centre to NTU
- Get off at the Administration Building (50 Nanyang Avenue).

Option 2: MRT (train) then take BUS 179 at Pioneer Station

- From anywhere in Singapore, get to the East West Line and take the train going to Joo Koon.
- Get off at Pioneer Station (EW28). Turn left as you exit the MRT ticket gates.

- Get down the stairs and take Bus 179 at the bus stops a few stops away from the food court.

- Get off at Lee Wee Nam Library

TRANSPORTATION TO CONFERENCE SITE AT NTU

Option 3: MRT (train) then take BUS 199 at Boon Lay Station

- From anywhere in Singapore, get to the East West Line and take the train going to Joo Koon.
- Get off at Boon Lay Station (EW27).
- Go to the Boon Lay bus interchange (it's inside the shopping mall) and take Bus 199.
- Get off at Opposite Lee Wee Nam Library and walk up the pedestrian overpass.

Option 4: MRT (train) then take NTU-Pioneer Shuttle Bus (a.k.a Campus Rider) at Pioneer Station

- From anywhere in Singapore, get to the East West Line and take the train going to Joo Koon.
- Get off at Pioneer Station (EW28). Turn right as you exit the MRT ticket gates. Get down the stairs.
- Take the Campus Rider at Block 649A (the bus stop at the base of the stairs).
- Get off at Administration Building.

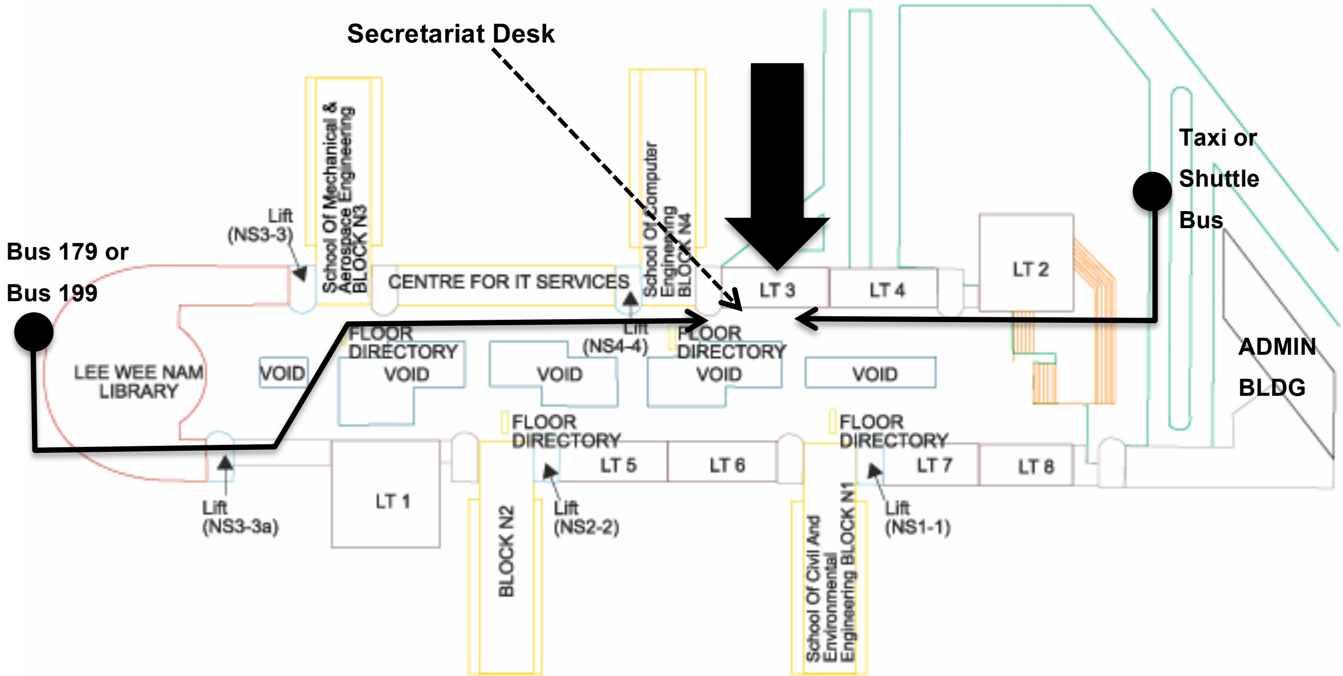
ADMINISTRATION BUILDING (Get off here if you take taxi or the Shuttle Bus from Pioneer)

LT3 is behind the Tan Chin Tuan Lecture Theatre
(across from this blue building, Admin Building)

LT3 is behind the Tan Chin Tuan Lecture Theatre
(go up the stairs, follow the arrow)

The conference are organized in three lecture theatres (LT):

a) **LT3: Block NS4-02-32**
b) **LT9: Block NS4-04-39**
c) **LT10: Block NS4-04-41**



Floor plan of NS4, Level 2

View coming from Lee Wee Nam Library

View coming from Administration Building

SINGAPORE PRACTICAL INFORMATION

Time: GMT+8

Currency: SGD (Singapore Dollars)
Foreign currency and traveller cheques can be exchanged at the Changi International Airport, hotels, shops and licensed money changers. No commission is charged. Visitors are discouraged from changing money with unlicensed money changers.

Climate
Tropical climate with temperatures ranging from a low of 24◦C to a high of around 31◦C. Rainfall usually takes the form of sudden showers and storms.

Language
English is the common language spoken by all. Signs in Singapore are also written in English.

Electricity
Singapore uses the "Type G" (British 3-pin) electrical plug. Voltage is 230V, 50Hz.

Goods and Services (GST) Tax
When you shop in Singapore, a 7% Goods and Services (GST) Tax is applicable and is normally included in the price of items. Tourists may claim refund of GST paid on goods purchased from retailers participating in the Tourist Refund Scheme. GST is refundable if visitors spend a combined sum of at least S$100 from the same retailer, and the Refund Form should be obtained from the retailer. The goods must be taken out of Singapore within two months from the date of purchase. For more information, please visit www.globalrefund.com.

Useful Numbers
Police: 999
Ambulance/Fire Brigade: 995

Tourism
More information on Singapore can be found in http://www.visitsingapore.com.