METR 4900
Thesis Research Poster Symposium

October 24, 2014

The robotics design lab
<table>
<thead>
<tr>
<th>Time</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:45 - 10:00 AM</td>
<td>Thomas Kearney - Automatic Calibration of XY printer substrates (SpnS, PP)</td>
</tr>
<tr>
<td>12:30 PM - 12:45 PM</td>
<td>Ben Merange - IMU Array for Low Cost Inertial Navigation (SpnS, MK)</td>
</tr>
<tr>
<td>3:00 PM - 3:15 PM</td>
<td>Christopher Hourigan - 3D Printer Calibration (SpnS, PP)</td>
</tr>
<tr>
<td>3:15 PM - 3:30 PM</td>
<td>Nicholas Hourigan - Recyclable UAV (PP, Spns)</td>
</tr>
<tr>
<td>3:30 PM - 3:45 PM</td>
<td>Cody Payne - Demo in 45-203 (MK/DM, PP)</td>
</tr>
<tr>
<td>3:45 PM - 4:00 PM</td>
<td>Break</td>
</tr>
<tr>
<td>4:00 PM - 4:15 PM</td>
<td>Ye Ding - The Project Magithoscope (UA, SpnS)</td>
</tr>
<tr>
<td>4:15 PM - 4:30 PM</td>
<td>Jameel - Scaled Loader Automation (MK, SpnS)</td>
</tr>
<tr>
<td>4:30 PM - 4:45 PM</td>
<td>Timothy Filmer - Paper Plane (PP, SpnS)</td>
</tr>
<tr>
<td>4:45 PM - 5:00 PM</td>
<td>Break</td>
</tr>
<tr>
<td>5:00 PM - 5:15 PM</td>
<td>Emma Kidman - Diving Coach Monitor (SpnS, PP)</td>
</tr>
<tr>
<td>5:15 PM - 5:30 PM</td>
<td>Michael McLeod - ABS Robot Arm for Ultrasound Assistance (SpnS, HK)</td>
</tr>
<tr>
<td>5:30 PM - 5:45 PM</td>
<td>Joshua Song - POMDP for Human Tracking and Assistance (HK, MK)</td>
</tr>
<tr>
<td>5:45 PM - 6:00 PM</td>
<td>Hongyang Zhou - Path planning using MILP (MK,HK)</td>
</tr>
</tbody>
</table>
IMU Array for Low Cost Strap-Down Inertial Navigation

Ben Merange under supervision of Dr Surya P.N. Singh

**MOTIVATION**
Modern microelectromechanical systems (MEMS) have addressed the issues of cost and size, however have done so by sacrificing accuracy. Inertial navigation requires a highly accurate orientation model to allow estimation of position from acceleration measurements. A fused array of IMUs has the potential to provide sufficient accuracy for a low cost compact motion tracking system. Such a system would have a variety of applications in GPS-denied navigation and motion capture.

**AIMS**
- Develop a real-time synchronised data acquisition package for the BEE-Board on-board IMU.
- Assess the reliability of orientation estimates using a direct approach.
- Implement a Kalman-based filter for state estimation and fusion of accelerometer and gyroscope data.
- Implement Kalman-based fusion of an IMU array.
- Design and build a test system for motion under specified conditions.
- Assess the feasibility of a MEMS IMU array for inertial navigation.

**APPROACH**
BEE-Board (UQ design) used to act as an IMU with data interface. On-board real-time clock synchronised between boards to output sync pulses. Unscented Kalman Filter (UKF) chosen to allow nonlinear state estimation. UKF assumes Gaussian noise distribution; a good model of stationary MEMS noise.

The information of the print bed is captured over a grid, and is used to determine the planar equation. The Moore-Penrose pseudoinverse is used to solve the overdetermined system of linear equations (Figure 5).

Multiple options were implemented to utilise the planar equation and calibrate the printer. The following outputs are printed:
- X and Y rotation angles of the print bed.
- The required thumb screw adjustments to level the print bed.
- 3-Point positions to feed into external slicing software.

The system is able to assist a user with the calibration process, accuracy errors however, it cannot do so completely independently. Whilst achieving the project aims. Due to the precision and accuracy of this process is then checked. The following image shows the results of an uncalibrated sensor (Figure 4). For a calibrated sensor, the traceable accuracy error is around 0.2 mm.

**RESULTS**
Direct orientation estimates showed substantial drift following calibration. Orientation estimates were reliable under sensor fusion; real-time model showed limited drift with extended motion, averaging 2 degrees/min along the gravitational axis.

Accelometer bias could not be reliably calibrated at run-time. Sensor and axis cross-correlation caused complications in linear acceleration estimation.

**CONCLUSION**
IMU array fusion showed significant improvement in orientation estimation over estimates with a single IMU. Real-time inertial navigation using low cost MEMS IMUs is not feasible due to unpredictable sensor cross-correlation and (\(n^2\)) computational complexity with sensor fusion dimension. Post-processing may yield an increase in accuracy, however UKF calibration would become extremely difficult.

**ALGORITHM**

<table>
<thead>
<tr>
<th>State:</th>
<th>( x_{t+1} = A x_t + B u_t + w_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement:</td>
<td>( y_t = C x_{t} + v_t )</td>
</tr>
<tr>
<td>Generalized Sigma Points:</td>
<td>(state factor ( y ))</td>
</tr>
<tr>
<td>State Prediction:</td>
<td>(mean) ( \hat{x}_{t} = \tilde{F} \hat{x}_t )</td>
</tr>
<tr>
<td>Measurement Update:</td>
<td>(covariance) ( P_{t} = \tilde{P}_{t} )</td>
</tr>
</tbody>
</table>

**METHODOLOGY & RESULTS**

**Mechanical and Electrical**
A Sharp GP2D120 sensor communicates via an Arduino Nano, and this independent system is housed in a 3D printed case and mount.

**Software**
The computation functions are implemented in a Python program, which are accessible via a command line interface.

**Sensor Distances**
A precise sensor distance is calculated by polling the sensor for multiple readings, and taking the maximum likelihood estimation of the distribution; which is referred to as the weighted mode (Figure 2).

To ensure that the error is traceable, the software can conduct a precision check on the sensor. Multiple sensor readings are captured and the range calculated. The results show that a precision of around 0.03 mm is achievable (Figure 3).

**Sensor Calibration and Checking Accuracy**
The sensor is calibrated by fitting a quadratic curve, via least squares, to captured distances at a range of known heights. The accuracy of this process is then checked. The following image shows the results of an uncalibrated sensor (Figure 4). For a calibrated sensor, the traceable accuracy error is around 0.2 mm.

**RESULTS**
Calibration of a 3D Printer via a Non-Contact Sensor

Christopher Hourigan under the supervision of Dr. Surya Singh

**MOTIVATION**
Affordable Fused Deposition Modelling (FDM) 3D printers are becoming more prolific, yet difficulties associated with calibrating and maintaining them remain an issue. There are very few low-end printers on the market which can quickly calibrate autonomously and without contacting the printer bed; subsequently, this is the topic of this thesis.

**AIMS**
This project aims were to develop a system which allows a 3D FDM printer to calculate the required changes that must be made to its control surfaces to result in calibration. Calibration, in this context, means that the movement of the print head is aligned with the print bed. To achieve this, the system aims were to be:
- Low Cost
- Quick
- Adaptable
- Integrable

**METHODOLOGY & RESULTS**

**Mechanical and Electrical**
A Sharp GP2D120 sensor communicates via an Arduino Nano, and this independent system is housed in a 3D printed case and mount.

**Software**
The computation functions are implemented in a Python program, which are accessible via a command line interface.

**Sensor Distances**
A precise sensor distance is calculated by polling the sensor for multiple readings, and taking the maximum likelihood estimation of the distribution; which is referred to as the weighted mode (Figure 2).

**Tracing Precision Error**
To ensure that the error is traceable, the software can conduct a precision check on the sensor. Multiple sensor readings are captured and the range calculated. The results show that a precision of around 0.03 mm is achievable (Figure 3).

**RESULTS**
Calibrating the 3D Printer
Multiple options were implemented to utilise the planar equation and calibrate the printer. The following outputs are printed:
- X and Y rotation angles of the print bed.
- The required thumb screw adjustments to level the print bed.
- 3-Point positions to feed into external slicing software.

The system is able to assist a user with the calibration process, whilst achieving the project aims. Due to the precision and accuracy errors however, it cannot do so completely independently.
**Recyclable and Biodegradable UAV Glider Airframe**

Nicholas Hourigan under the supervision of Dr. Paul Pounds

**MOTIVATION**
To design a small scale glider airframe with the intentional lifetime of a single flight. On completion of the mission the airframe was designed to be either recycled, or biodegrade into the environment to cause minimal impact to the surroundings.

**AIMS**
- Achieve a glide slope of 40:1.
- Be extremely low cost and simple to manufacture.
- Use a recycled cardboard moulded pulp material for the airframe.
- To be launched via weather balloon at approximately 30'000m.

**MATERIAL - MOULDED PULP**
This packaging material most commonly found in egg cartons was selected due to its recyclable/biodegradable nature and formability which allowed it to be easily cast into a mould to produce an airframe. Upon experimentation and research it was found that the material has suitable properties for a small scale airframe; these properties are:

\[ p = 413.73 \text{ kg/m}^3 \]
\[ E = 339.37 \text{ MPa} \]
\[ s = 0.637 \text{ MPa} \]
\[ \alpha = 0.00187 \]
Shrinkage = 5.89%

**MOULD TESTING**
To test the castability of moulded pulp a flying wing mould was designed with twist, sweep, taper, multiple airfoils and polyedred to test the limits of casting. This mould was 3D printed with ABS and heated in the oven at 75 degrees celsius with the moulded pulp casting still within to improve surface finish and shape of the final product. It was found that due to shrinkage the surface was uneven and would require finishing to avoid flow separation. Bees wax was therefore used to increase the surface finish and waterproof the airframe.

**AIRFOIL SELECTION**
The selection of the airfoil determined the limitations and design characteristics of the airframe. The span of the aircraft was limited to 40cm due to manufacturing limitations to ensure the mould was cheap to produce. Therefore the design envelope was aimed at low Reynolds numbers. The Reynolds Number varied significantly from 9495 to 44780 due to the extreme range of altitudes faced by the airfoil. This is still in the laminar flow region which is relatively unexplored. The AG19 Drela airfoil was selected due to polar data analysis and research. The airfoil has a max camber of 2.2% and max thickness of 5.4% which in simulation resulted in the best glideslope.

**RESULTS**
- Be extremely low cost and simple to manufacture.
- Use a recycled cardboard moulded pulp material for the airframe.
- To be launched via weather balloon at approximately 30'000m.

**FINAL DESIGN**
Resulting from the MATLAB simulations a flying wing was designed in XFLRS utilizing the aforementioned design parameters. A flying wing was designed over a 1985. Physiopathol Respir.

**REFERENCES**

---

**ABSTRACT**

Commercial stethoscopes have a frequency response of ~10 to 1,600 Hz [1], compared to the average adult human ear’s ~20 to 20,000 Hz—an underutilization of the ears’ bandwidth.

Sudden, discontinuous coughs and wheezes have components beyond human hearing range [2] (“Higher frequency sounds”) – hence we explore the use of these sounds for diagnosis.

A Magithescpe® was designed for this thesis. In addition to the capability of a standard stethoscope, a Magithescpe can also reproduce higher frequency sounds at human hearing range.

**TECHNICAL BACKGROUND**
- To perceive these higher frequency sounds, the input is demodulated.
- The demodulation process produces an output (red) that describes an instantaneous parameter of the input (blue).

**DESIGN**

![Diagram of Magithescpe®](image)

- **Amplitude Demodulation (AD)**
- **Frequency Demodulation (FD)**

**RESULTS**
- **Normal (chestpiece):** 30 to 2,000 Hz
  - Auscultations (heartbeats) were audible, and waveforms clearly show peaks corresponding to heart contractions.
- **High frequency tweeters used to produce sounds resulting in predictable outputs.**
  - Full frequency generative frequency sweep.
  - Higher frequency components of coughs and claps into microphones were demodulated, audible in all three bands.

**CURRENT & FUTURE DEVELOPMENT**
- Human evaluation trial planned, currently undergoing ethics approval.
- Detection of other higher frequency sounds originating from human body
- Further (professional) refinement to design is necessary for manufacture/commercialisation.

**CONCLUSION**
- Different forms of demodulation produce reinterpretations of sounds.
- Portable, convenient “all-in-one” device, allowing the listener to hear these sounds conveys truly new information.
- Hence this product is highly feasible for future research and application in medical practice.

**REFERENCES**
**MOTIVATION**

Paper is a biodegradable, lightweight material that could be appropriate for building micro UAVs.

**Aims**

To model a paper plane glider to fly from Sydney to Brisbane.

- Sufficient glide slope and payload
- Passively stability is desirable
- Generate appropriate navigational data to make this flight
- Incorporate current weather data
- Generate off-line and be able to store on a microcontroller

**MECHANICAL MODEL**

**Requirements**

- Glide 750km from an initial height of 40km
- Minimum glide slope of 25

**2D Design**

- Thin airflow that maximizes Cl/Cd while maintaining an acceptable Cm
- Work across a range of Reynolds numbers

- Optimal Cl/Cd of 30 at 2.5° AOA
- Used the characteristics of this wing across a range of Reynolds numbers in simulating flight characteristics across a range of altitudes to provide an accurate aerodynamic model for the navigation

**NAVIGATION**

**Atmospheric Data**

- US Standard Atmosphere
- US NWS Global Forecast System for wind data at different altitudes

**State and Action Space**

- Discrétised state space into latitude, longitude and height. Action broken into possible new states (blue squares) from the current state (green square)

**Cost Equation**

- Analogous to height required to reach goal, cost of the goal state is set to 0
- Cost of an action is the height required to reach the desired state with the attitudes wind speed and plane speed

**Minimising the Value Equation**

- Using value iteration across the state spaces, this is given an optimal solution but has poor timing complexity, where value is calculated with:

\[ V(s) = \arg \min_a (V(s+1) + C(s, a)) \]

**Generating the Decisions**

- Map made of optimizing across actions
- The heading is broken into N/S & E/W components to avoid discontinuities
- Surface fit is applied to contract the large number of headings into polynomial coefficients

**Future Improvements**

Numerous future improvements can be made to this concept and these are outlined below.

- Firstly, the design failed to meet one of the aims of offering three degrees of freedom. This was a conscious design choice and was made because adding in rotational movement severely added to the complexity of the design.
- Second, due to manufacturing limitations and issues the design was not built from the desired material and was also not built to the desired tolerances.

**SIMULATING THE FLIGHT**

- Iterating over time, velocity and sink rate are calculated based on height, the heading is calculated based on height, the heading is based off the decisions generated
- Error added to the heading with a normal distribution with range (-15, 15)
- Simulation using weather data from 19/10/14

**Outcomes**

The final product was successful in proving a concept however there were numerous findings and failings.

- Firstly, the design failed to meet one of the aims of offering three degrees of freedom. This was a conscious design choice and was made because adding in rotational movement severely added to the complexity of the design.
- Secondly, due to manufacturing limitations issues the design was not built from the desired material and was also not built to the desired tolerances.

**CONCLUSION**

- 2D mechanical design suggests a design may be possible, but this is yet to be successfully taken to 3 dimensions
- The value iteration was verified by simulating the navigation against real world wind data and with randomised uncertainty
- The parameterization of the decision rules was successful but could be made to be more memory efficient

---

**ABS ROBOT ARM FOR ULTRASOUND ASSISTANCE**

**Method**

The design arrived at was based on a parallel mechanism with spring counter balancing, similar to the timeless Angle poise Lamp.

Several materials were investigated for the design including injection molded plastics, foam, aluminium and a laminate of honeycomb cardboard and plastic.

The final material selected was 5mm Coreflute plastic, a polypolypropylene plastic board with hollow cores running through it. It was selected for its strength, fatigue resistance, low weight, low cost and its ability to be recycled.

**Outcomes**

The final product was successful in proving a concept however there were numerous findings and failings.

- Firstly, the design failed to meet one of the aims of offering three degrees of freedom. This was a conscious design choice and was made because adding in rotational movement severely added to the complexity of the design.
- Secondly, due to manufacturing limitations issues the design was not built from the desired material and was also not built to the desired tolerances.

The folded plastic spring design was not successful in testing and as such was removed from the final design.

**Future Improvements**

Numerous future improvements can be made to this concept and these are outlined below.

- Several potential materials were discovered during the design process, with the most exciting being a biodegradable plastic which can be injection molded and was also able to be sterilised with gamma radiation. This would mean that the design would have to be modified to suit the new material but the basic concept would still be possible.
- Another potential improvement is the addition of circuitry to assist in the generation of a pseudo 3D image. If a cardboard plastic laminate material was used printable circuit technology could potentially be utilised to incorporate the circuit into the structure itself.
- Finally, more research and could be done into the plastic spring design incorporating different materials and geometries could potentially lead to an easier to manufacture product which is fully biodegradable.
POMDP for Human Tracking and Assistance
Joshua Song  Supervisor: Dr. Hanna Kurniawati

THE PROBLEM

Existing systems (e.g., Kiva) need the environment to be well specified, but there is interest in robots that can assist a human in an uncertain environment.

BACKGROUND

POMDP Controller

Belief Estimation

Belief

Policy

Observation

Robot

Action

Partialy Observable Markov Decision Processes provide a framework for planning under uncertainty. A belief is the probability distribution over possible states. A solver will find the optimal policy, which is a mapping from beliefs to actions that will maximise the reward.

IMPLEMENTATION

Obstacle avoidance

This feature is being implemented by introducing an arbitrary large value M which will shift any variable outside the working environment. Combining with a binary variable which can act as a switch, a set of constraints can be established to ensure the vehicle is always outside the obstacle.

Pad obstacles to avoid corner cutting

As the program only consider the location of the vehicle at the end of each time step, it is possible for the vehicle to be collision free at the end of each time step but still collide with the obstacle within those time steps. One solution for this is to pad the obstacles by a small length which is dependent upon the size of the time step and the maximum distance between the adjacent two state.

Waypoint constraints

Using the combination of big M and a set of binary variables which will take the value of 1 if the position of the vehicle is the same as the position of the waypoints. Another summation constraint is then added to ensure that the waypoint is being visited at a time step before the end of horizon.

Rendezvous constraints

For simplicity purpose, the position of the vehicle to be visited at each time step are known prior to the simulation. By applying similar constraints as waypoint constraints, the program can compute the rendezvous trajectory successfully.

Solution’s Strong Points

- Robot Operating System (ROS) interface makes POMDP accessible to more researchers.
- The POMDP solver is capable of solving problems fast enough for practical applications, and handles changes to the model and number of state variables.
- Hence the motion planner is able to handle uncertainty in control and sensing, and make good decisions despite not fully knowing the environment layout.
- The solver can handle changing number of targets.

Future Direction

- Refine the algorithm
- Test on an actual robot

RESULT

As can be seen form the graphs above, the program successfully avoid colliding with obstacles, visited all the waypoint that was assigned, successfully performs rendezvous with another moving vehicle and minimizing the fuel and time usage to reach the goal.

CONCLUSION

Overall, Mixed Integer Linear Programming is a powerful tool which has many amazing applications in many fields when the problem involves optimization. However, the computational time used to solve a problem can vary with the size of the problem. As can be seen from the graph below, the computational time of the problem increases in an exponential manner.

For the application of pathplanning an optimum trajectory without any time constraints, Linear Programming is a reliable tool with good results. However, if a problem needs to be solved online (a dynamic environment) within a limited amount of time, the performance of Linear Programming might not be as good as other methods/algorithms.
Motivation

Localisation is not always an easy task for robots – much of the behind the scenes processing in modern GPS devices is extremely complex.

A GPS is very inaccurate over short term but good over a long term, while an accelerometer is the opposite (and completely unusable long term).

This thesis aims to combine these two inputs using a Kalman filter to localise a device far more accurately than any single source of data.

Aims

• Use one or more Beaglebone Blacks with connected via WiFi
• Create an ad-hoc network between these devices
• Attach an IMU
• Use a camera and image processing to produce a simulated GPS signal (including error)
• Combine these inputs with a Kalman filter

Kalman Filter

Four filters have been used in the solution: the first takes velocity from the GPS data and acceleration from the IMU and combines them for a very accurate velocity – this is then combined with the GPS positional data to determine position. Both the filters are applied to both x and y axis separately.

Hardware

Beaglebone Black
A small embedded Linux computer running Ubuntu. Will be used as the robot. Equipped with a USB WiFi card.

IMU - MPU6050
An I2C accelerometer and gyroscope compatible with the Beaglebone.

Software

Robot Operating System
The Beaglebone is running ROS – or Robot Operating System, which provides structure and APIs for extending the code in future projects.

reactTIVision
A laptop connected to a camera is running image processing software and producing pseudo-GPS coordinates. A server on the laptop adds some error to simulate GPS inaccuracy and forwards that data to the Beaglebone.

Results

The results so far are not as accurate as hoped, with the filter failing to reduce the amount of noise significantly. The following graph is an example of a typical localisation accuracy. The red line represents the original noisy GPS data, and the blue the Kalman data (scale in cm).

Improvements can be made in the following areas:

• IMU read frequency
• Kalman constants
• Kalman filter speed – currently cannot keep up with IMU
• Scale of experiment – actual GPS to IMU error scale significantly different to current setup.