Izak9: Enhancing mathematics education through play

Qubizm
Innovation Voucher Project: IV0615137
Report

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Introduction

The main objective of the project is to investigate and, where possible, test the potential technological solutions to a client submitted request. Specifically; the client is interested in the ability to track the three dimensional position and rotation of cube shaped objects within a relatively confined space. The real-time data gathered can then be applied in the context learning analytics where we review how children approach, and solve mathematical problems.

Overview

Technological Consideration

In order to provide the requested functionality it is important to consider that the technical developments actually fall into two major categories and, as such, are approached separately. Firstly the client has the need to identify real time rotation of each object in three dimensions; X Y and Z or more commonly referred to as Pitch, Roll and Yaw.

Secondly the client has the requirement to identify each objects position in relative 3D space and most importantly; object position in relation to the other objects within the same immediate location.

Taking the previously mentioned factors into account, each problem is approached separately, however, we have been mindful of solution combinations where the requested functionality could be achieved through the combination of approaches.

The requested functionality presents a a particular challenge. It is important to highlight that the provision of a working prototype is beyond the scope of the current work. With this in mind all effort has been directed at evaluating a set of possible technical solutions. Each was explored and points made regarding candidates for future work.

Research approach 1 – Measuring Object Rotation in 3D space

The L3GD20H 3-axis gyro and an LSM303D 3-axis accelerometer and 3-axis magnetometer were coupled via the I²C interface to Arduino to access nine independent rotation, acceleration, and magnetic measurements that were used to calculate the sensor's absolute orientation. The two ICs were accessed through a shared I²C/TWI interface, allowing the sensors to be addressed individually via a single clock line and a single data line.
The nine independent rotation, acceleration, and magnetic readings (sometimes called 9DOF) provide all the data needed to make an attitude and heading reference system (AHRS). With an appropriate algorithm, a micro-controller or computer can use the data to calculate the orientation of the MinIMU board. The gyroscope is used to very accurately track rotation on a short timescale, while the accelerometer and compass can help compensate for gyro drift over time by providing an absolute frame of reference. The resulting data manipulated and

used to directly manipulate the pitch, roll and yaw of a 3D model, leveraging Max 7 (Cycling 74) as the development platform.

The video here is offered as reference to the resulting early development, which was further enhanced as development area one: https://vimeo.com/129584143

Approach 1 discussion:
The usage of Gyroscope technologies coupled with micro-controller allows for accurate rotational data to be gathered and manipulated computationally. As a solo development however, it does not fully meet the client requirements as this technology allows for no sense of positional accuracy in relation to other objects in the same space. In other words; whilst it can tell us accurately the rotational position it can not give us position in space when compared to other objects in the same space, a prime requirement of the client. As such further supporting technologies would be required to be implemented in tandem in order to meet the client request.

Research approach 2 – Measuring Object Relevant Position

Following discussion with the client, where the two main approaches were highlighted (electronic sensors versus optical sensing i.e. camera tracking) a preference for a solely electronic sensing mechanism was expressed.

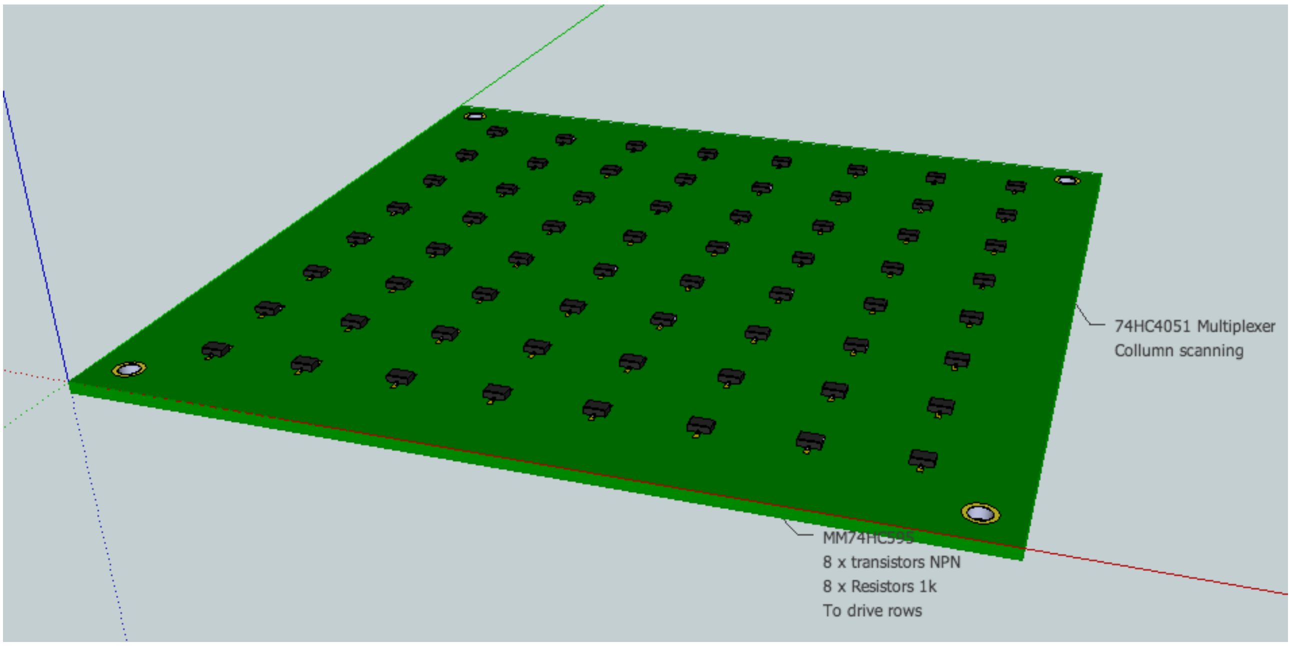
Challenges
Each object must be capable of transmitting some form of identification whilst at the same time being able to sense the identification values of the objects in its near vicinity.

RFID tags.
After thoroughly researching and testing RFID tags were dismissed as a viable solution as they are incapable of recognising one another within such confined space and are much more appropriate for larger scale areas.

Binary face encoding/decoding with magnetics and magnetic sensors.

Introduction
In order to identify individual faces of the objects in question each face of each object must both transmit and be sensitive to receiving some form of identifying characteristic. One solution explored is depicted in figure 1 below. The proposal is for the implementation of face embedded magnetics with opposing faces being sensitive to magnetic arrangements.

Figure 1 above depicts the potential sensor array, which features 64 hall effect sensor of type: Allegro A1321ELHLT, a 74HC4051 Multiplexer used for column scanning analog data, a MM74HC595 shift register and 8 x BC847 NPN transistors which function to source the current source to rows. This arrangement could be considered to be a binary magnetic sensing array and coupling such with magnetic arrangements on the opposing face of the adjacent cube would allow face identity and positional information to be gleaned.



The proposed solution has potential to provide the functionality requested by the client however, it is electronically complex and expensive to implement.

During preliminary tests the magnetic field caused interference with the primary development (Rotation compass) as they too are reliant on magnetism for sensing of rotation.The cost per cube for production cost is expected to exceed £400, couple this with the inherent complexity of construction and overall fragility of the technology it becomes clear that this solution is non viable both practically and financially.

The use of magnetic “fingerprinting” of this type is novel however and could offer potential for unique identification in other fields.

Conclusion:

The results of the current study have demonstrated that a purely hardware solution is non viable as it is too fragile, for example, if a child were to drop one of the units it will likely cease working effectively. Also, the cost to implement is excessive and perhaps unnecessary. The total costing of implementing the technologies explored is estimated to be in the region of £500 per unit, or £13,500 per kit of 27 Cubes.

Combining these factors leads to a recommendation that we explore alternate camera tracking technologies.

Forward:
Following a review of computer vision methods, a technique known as *Fiducial Tracking* was highlighted as a likely solution candidate

(fig. 2: An example of a fiducial marker)

A *fiducial marker* or *fiducial* could be described as a unique identification marker that when placed in the field of view of a camera based imaging system can be used as a point of reference or a measure of position. The process of embedding unique fiducial markers to the face of each cube would make the faces uniquely identifiable by the imaging system and would allow each object to be tracked at high rate (60 frames per second) without the requirement of custom or expensive hardware.

System overview:
The combination of multiple high frame rate camera systems and the leveraging of existing computer vision methods, specifically fiducial marker tracking, would allow for the accurate tracking of all objects within a confined working area as per the client request. Three camera systems are recommended, although an additional overhead camera may be required. These cameras systems work in combination to collectively track the position of each cube with a high degree of accuracy.

(Fig. 3: Proposed physical arrangement: Fiducial tracking system)

Estimated Costing

Research and Development Software:
Estimated **£25,000 – £30,000** R&D/Software development.

Hardware Computing:
Apple 13" iMac Pro 3.1GHz Dual-core Intel Core i7: est.- **£2129.00**

Hardware Cameras:
4 x $120.00 plus import duty – est. £100.00ea. - **£400.00**
for example: http://www.kurokesu.com/shop/CAMUSB1
Note: More expensive Firewire camera systems may be deemed to perform better.

Tridpods/Fixtures:
est. £1,200

Total estimated costing - **£29,629.00 - £33,429.00**

Estimated Schedule

We estimate that an optical tracking system could be delivered within 9 to 12 months of full-time development. In the case of strict scheduling the development could take up to 24 months.