Game Controller Hacking for Fun and Profit

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Abstract—**This paper discusses experiences teaching an undergraduate computing subject that engages students through game controller hacking. In particular it presents the hacked USB joystick as a cheap interface technology that enables a wide variety of projects with applications both inside and outside the classroom.**

Keywords-game controllers; hacking; video games; computer science education

I. Introduction

Programming simple board games like tic-tac-toe, reversi, and connect four have long been a staple of introductory programming courses as well as specialised higher-level courses like Artificial Intelligence (AI). More recently the use of game engines in teaching has provided an opportunity to engage student interest beyond programming and AI to include topics like graphics and animation, networking, scripting, performance and scalability [1].

Robotics has also been used both in computing and engineering courses as a way of engaging, attracting, and retaining students while teaching them a wide range of subjects [2]. In the past, the cost of including robotics was often prohibitive but the introduction of Lego Mindstorms NXT kits has made the inclusion of robotics in the curriculum of both university and school classrooms more affordable [3]. Robot soccer competitions are also seen as a participation incentive for current students, a way to attract future students, and an opportunity to promote universities.

In keeping with these approaches, this paper discusses experiences teaching an undergraduate computing subject that engages students through game controller hacking. In particular it presents the hacked joystick as a cheap interface technology that enables a wide variety of projects that can be used both inside and outside the classroom. In this context the use of the terms "hacking" and "profit" in the title should not imply any attempt to siphon or extort money via computer. Instead, there is educational profit to be had by creatively modifying or extending both game controllers and games beyond their original design.

The next section of the paper provides an overview of the controller hardware used in teaching the course before the software is introduced in section III. Sections IV then discusses a number of projects using hacked controllers and the educational opportunities they afford both inside and outside of the classroom. Finally, conclusions and future directions for this work are presented in Section V.

II. Hardware

A summary of sixteen projects created using hacked game controllers appears in Fig. 1. Circles represent the three game controller types: the Nintendo Wii-remote (or "Wii-mote"), a hacked joystick, and a computer mouse. The boxes represent the different projects and the thick lines connect the projects to the controllers used in their implementation. For example, the right-hand column contains projects that only use hacked joysticks, while the "Infrared (IR) rail shooter gun" project uses a hacked joystick in conjunction with a Wii-mote. An overview of each of the controller types is presented in the following sections.

A. Hacked Joysticks

The modern joystick is typified by Son'y Dualshock controller for the Playstation 2 game console. It includes sixteen digital inputs (four direction pad keys plus twelve buttons), four analog inputs (two dual-axis analog joysticks) and two outputs in the form of vibration or "rumble" motors that are used to provide haptic feedback. USB clones of the Dualshock controller for use with personal computers are also available, selling for less than $4 (US) and with a simple hack they become a cheap, plug and play, interface device that enables a diverse range of projects.

The hack or modification involves the addition of either a nine or twenty-three pin D-sub-miniature connector to the underside of the joystick. See Fig. 2. These are standard, cheap, readily available connectors that have historically been used for serial and printer connections respectively. The choice of nine or twenty-three pins depends on the number of inputs and outputs required. The connector is patched transparently onto the printed circuit board of the controller so that its normal operation is unimpaired but the buttons can now be bypassed and connected to external switches. This simple hardware abstraction permits signals sent via the D-sub connector to appear as if they are responses to button presses and joystick movement on the game controller itself. This is an example of opportunistic design and it enables what Hartmann, Doorley and Klemmer call a “mashup” – the ad hoc design and combination of hardware and software [4]. Rekimoto and Wang use a similar approach by introducing a new type of game interaction, which is interfaced using a hacked Dualshock controller [5].

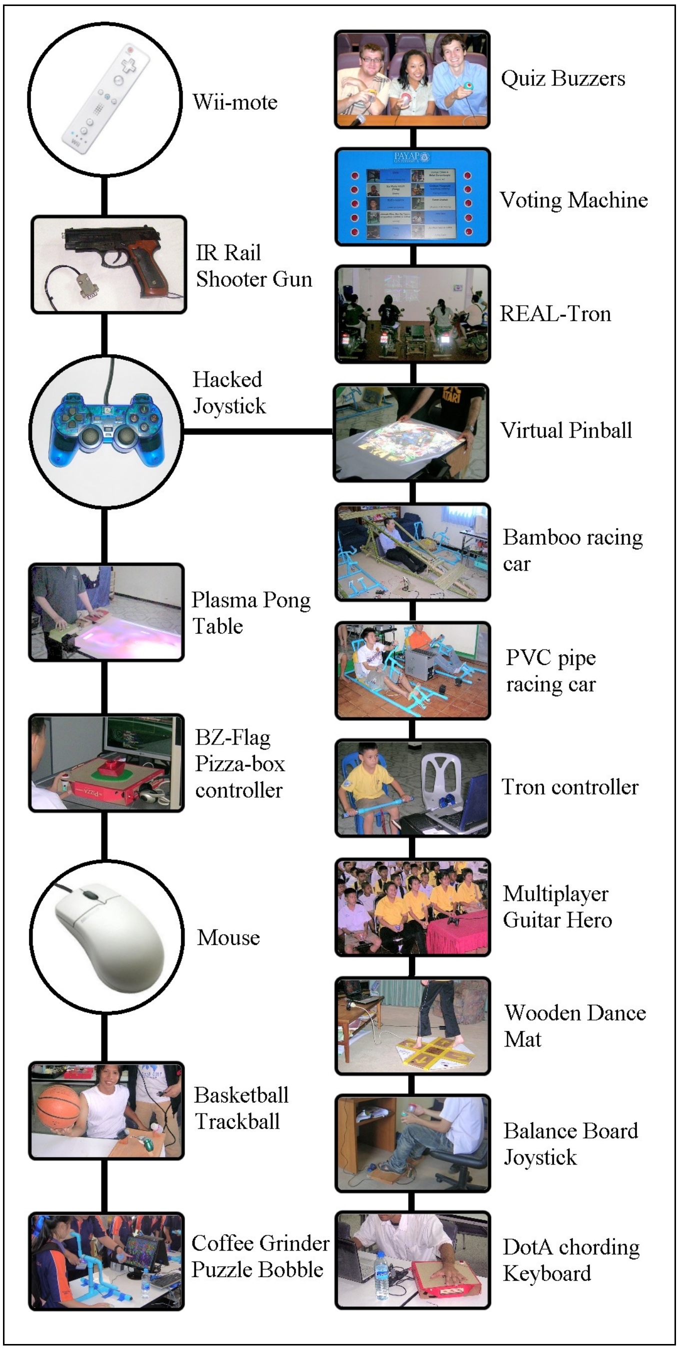

Figure 1. Sixteen projects that use hacked game controllers.

Figure 2. A Dualshock-like USB joystick (left) and a hacked joystick showing the nine-pin D-sub-miniature connector mounted underneath the controller and the analog joystick axis switch (right).

In addition to external switches being used to create phantom button presses, variable resistors can also be patched into the joystick axes to give analog inputs which can be used, for example, to provide steering in driving games/simulations. The switch to the right of the cable at the top of the hacked joystick in Fig. 2 is used to switch control from one axis of the internal analog joystick to an external variable input. External rumble motors can also be connected which, without their off-center weights, provide smooth, variable speed motors under software control. If these are connected to wheels or legs then you have the basis of a cheap, USB-powered (albeit tethered) robotics platform.

B. *Mouse*

The common desktop mouse is another cheap, flexible, and readily available interface device. Most modern optical "mice" provide five digital inputs, (left and right buttons, scroll-wheel click, scroll up/down), and two analog inputs (the horizontal and vertical axes). By turning the mouse upside down and fixing it in place it is possible to use it to detect the speed and direction of objects passing over it. Details of a project that uses this approach are presented in Section IV where a model tank is moved forward, backwards, left, or right over an inverted mouse to steer an army tank in a computer game.

A mouse can also be hacked using the same approach described for joysticks to add a connector giving external access to any of the mouse buttons or the scroll-wheel. However, if used in conjunction with a keyboard or hacked joystick then input remapping software can often be used to emulate mouse clicks from a different controller which leaves the mouse unmodified.

C. *Wii-mote*

Despite being the least powerful console of its generation the Nintendo Wii has been the best selling because of the game-play afforded by its novel controller – the Wii-mote. Each battery powered Wii-mote connects to the console via Bluetooth and includes a three-axis accelerometer, a high resolution IR camera, ten digital inputs (four direction pad keys plus six buttons), and six outputs (four LEDs, a speaker, and a rumble motor).

While it is the most expensive of the three controllers discussed here at approximately $40 US, it can be connected to a personal computer via Bluetooth and does not require any hacking of the controller itself. The ability to pair the Wii-mote with hand-held computing device like Apple's iPhone and iPad, or Android enabled devices also presents some interesting portable gaming and Human Computer Interaction (HCI) opportunities. Libraries for Wii-mote communication are available in a range of programming languages for Windows, Mac and Linux platforms and the Wii-mote as a teaching tool has already been incorporated in school classrooms and university curricula [6-8].

Using some of these libraries Lee has created and popularised a number of Wii-mote enabled hacks including: a white-board; finger, object, and head-tracking; and augmented spatial reality [9]. While these hacks do not require any modification to the controller itself they typically still require some electronics knowledge to construct one or more IR reference points using LEDs (although candles can also be used as a low-tech IR source). Having introduced the three controller types, the next section now turns to the glue that holds Hartmann, Doorley and Klemmer's "mashups" together: software.

III. Software

A hacked mouse or joystick can be used with any program that supports these controller types but few provide support for a Wii-mote. To use a Wii-mote for novel interaction with existing software requires access to the source code and suitable libraries so that the software can be modified to support this type of controller, or some method of disguising the input as something the software already recognises is required. Alternatively, a program may be expecting input from a joystick but the controller being used is actually a mouse and so some form of input re-mapping is often needed.

GlovePIE (Glove Programmable Input Editor) is a tool originally designed for re-mapping the output from P5 virtual reality gloves to emulate different outputs like joysticks, key-presses, mouse clicks, etc. [10]. It supports a diverse array of input devices which can be freely re-mapped to other devices via a scripting language and multiple keyboards, mice, and/or Wii-motes can be connected to a single computer. Mouse and keyboard input can also be "swallowed" or absorbed by GlovePIE so that these inputs can be captured and re-purposed. When used in conjunction with a virtual joystick driver it allows virtually limitless input re-mapping possibilities.

For example, the accelerometer in a Wii-mote, can be used to effectively create a wireless mouse, or joystick. As another example, Coffee Grinder Puzzle Bobble uses a controller based on the coffee-grinder winches used on ocean going racing yachts is used to play an arcade game. The player rotates crank handles made from PVC-pipe to control a character within the game. The rotation of the handles is detected using a hacked optical mouse, however, the game expects joystick input. A GlovePIE script and virtual joystick driver are used to convert output from the mouse into suitable input for the game. This is the type of novel gaming experience that students were tasked to create in the game controller hacking subject. In addition to GlovePIE the subject also made extensive use of games, emulators, simulators, modding tools, and USB-sniffing software - all of which were free and in most cases, open source.

IV. Controller hacking inside and outside the classroom

A game controller hacking subject was introduced as an elective available to second, third, and fourth year computing students. The subject was introduced with the intention of engaging students in interesting topics, combining and consolidating knowledge from existing areas of study, and providing opportunities that do not normally exist within the curriculum. The syllabus was designed to provide students with:

- An understanding of the historical context of modern gaming.
- Knowledge of current hardware and connectivity standards.
- An overview of issues at the interface of hardware and software.
- Practical experience in the design, construction and programming of novel game controllers.

As such it covered a broad range of topics including both the history of arcade and console games, an overview of modern games hardware and architectures, HCI and human factors principles, virtual reality, simulation, emulation, modding, piracy and copyright issues, basic electronics, and reverse engineering. The next section of the paper will discuss some of the projects used in the teaching of the subject and summarise the educational opportunities they present both inside and outside of the classroom. A brief overview of some student work resulting form the subject is also presented.

A. Army Tank Pizza Box Controller

National Thai science week is a Thailand-wide initiative that has been held annually since 1984 to promote science, particularly to school children. During this week the university runs activities in local schools to help promote science, to inspire students to pursue higher education, and to promote the university. The author was asked to provide some novel, interactive games for science week to use in local schools that were in keeping with a "recycling" theme. The result was a game where two teams of students play the online open source 3D first-person tank battle game BZFlag using controllers made with wood, chopsticks, pizza boxes, and other recycled materials [11]. An example controller appears on the left side of Fig. 3.

The controller consists of small wooden tank that sits on top of a pizza box. Inside the box is an upside-down optical mouse and control is provided by moving the model tank forward, backwards, left, or right over the mouse to move the in-game tank in the same direction. The students were challenged with a spatial reasoning task to work out how the mouse should be oriented in the box and to write a GlovePIE script to perform the required axis inversion. The use of every day materials encourages students to look for creative solutions and to view the world around them in new ways where common objects may have unexpected and surprising uses.

Figure 3. An army tank pizza box controller (left). The world map for the tank game is a giant version of the university's emblem (right).

Two buttons are also built into the box – one to fire the tank's cannon and another to "re-spawn" or re-enter the game if the player's tank has been destroyed. A prototype controller was constructed using a single hacked mouse but it was decided that the school's own computers would be used to run the event and it was not appropriate to hack their mice. An alternative solution was to use the school's mice in the boxes to detect the movement of the model tanks but the buttons were connect to the game via hacked joysticks. This gave students the opportunity to gain experience with soldering and joystick hacking which were skills that they would need for their own projects later in the semester.

To help promote the university to players of the game a custom map was created based on a giant version of the university's emblem as shown on the right in Fig. 3. The emblem was also visible from the players first-person perspective in the game on various signs and walls throughout the map.

The map is constructed using a text file that defines simple object primitives that can be manipulated using affine transformations like translation, rotation and scaling. This file was later re-used in a separate computer graphics subject to demonstrate the application of affine transformations and the game was also used to demonstrate the principles of anaglyph displays using red and cyan 3D glasses.

B. Plasma Pong and Virtual Pinball

Another project that uses mice for input is the Plasma Pong table. The game itself re-creates the classic two-player "tennis" game but the play-field contains a two dimensional plasma that effects the trajectory of the ball. Additionally the player's paddle can either eject or suck plasma to push the ball away from the paddle or to pull the ball towards it and this contributes to the overall turbulence of the play-field [12].

The Plasma Pong table uses an overhead mounted data projector to beam the play-field onto a white office table with a player standing at each end. Each player's controls consist of a box containing an upside down optical mouse and two buttons connected to the game computer via a hacked joystick. As the players use their palm to slide a piece of cardboard left or right over the top of the box their in-game paddle mimics their movements on the play-field projected in front of them. See Fig. 4.

Figure 4. The Plasma Pong table (left) and a virtual pinball machine with PVC water-pipe leg extensions (right).

A ready to play version of Plasma Pong has been used at parties to engage Thai students who are studying English. The table has also been used in a workshop at an English camp for Engineering students where they hack the joysticks, wire the connectors, and assemble the table themselves. While the single-player version of the game uses a mouse for input, the two-player version uses the keyboard for both players. This requires students to write a GlovePIE script that maps mouse movement along a single axis and button presses via the hacked joystick into the corresponding keystrokes expected by the game.

Students also need to use basic trigonometry to work out if it is possible to project an image that will fit onto the table's surface given the orientation of the game's screen (portrait or landscape), the specifications for the data projector, the dimensions of the table, and the ceiling height of the room. They must also consider how and where it may be possible to safely mount the data projector. If there is no existing projector or suitable mount then students can design and construct cages from PVC water-pipe to suspend projectors from beneath stair-cases, air-conditioners and various ceilings.

Virtual pinball uses a similar setup to the Plasma Pong table with the display from a pinball simulator projected onto the surface of a white office table in front of the user. A wooden box with flipper buttons, a rubber band powered plunger, and a mercury switch is attached underneath one end of the table to mimic the controls of a real pinball table. These controls are connected to the computer running the simulation via a hacked joystick. See Fig. 4.

These types of projects give students the opportunity to work at the interface between real and virtual environments where a representative object they construct in the physical world interacts with a simulation and the results are projected back into the real world. In the design and implementation of their projects, students must consider HCI and usability issues, and human factors principles. For example, the surface of a standard office table is not the same height as a pinball machine. The height of a table used to create a virtual pinball machine must be safely raised, using bricks or PVC pipe leg extensions, for comfortable play. Although Plasma Pong uses a similar setup, the controllers are mounted on the surface of the table rather than underneath it which provides a comfortable play height for most players.

Within a multimedia course students are given the opportunity to exercise their new found image and audio editing skills to create a themed pinball table by customising a blank play-field. The opportunity to play and interact with their creation on the virtual pinball machine is a substantial motivator for the students. Virtual pinball has also been used to promote the university in local schools and at other events via customised tables that feature the university logo. The realistic physics used in the pinball simulation and the fluid dynamics in Plamsa Pong also provide an opportunity to discuss topics like physics engines, graphics cards, Graphics Processing Units (GPUs), Physics Processing Units (PPUs) simulation, emulation, and copyright issues pertaining to both artwork and ROM images.

C. *Light-cycle Controllers*

A pair of customised motorcycle hand-grips was the inspiration for another project where a length PVC water-pipe was cut to match the dimensions of a motorcycle's handle-bars. The addition of hand-grips, a mercury switch, and turn buttons connected to a hacked joystick creates a controller used for playing the 3D light-cycle game GL-Tron [13]. A cheap immersive experience can be created where the player lies on an office table with the legs collapsed at one end and faces a rear-projection screen constructed using a data projector, paper and a clothes hanger. Stereo speakers are positioned on either side of the player's head and the game can be played from a first person view to provide a surprisingly compelling experience. See Fig. 5.

This idea was further expanded to use real motorcycles with buttons and mercury switches fitted to their handle-bars. Using a single data projector, a laptop, and a hacked joystick, up to four players can compete in a split-screen light-cycle game. This has been used to engage students at BBQs and English parties as well as participants at a BarCamp conference.

D. *PVC Water-pipe and Bamboo Racing Cars*

A student who played the original PVC connector described in the previous section said that he preferred to play driving games. As a result the concept was extended to create something like a go-kart chassis without wheels that can be connected to a computer via hacked joystick to play car racing games and simulators. See Fig. 6. Each car uses a variable resistor mounted on the steering shaft to provide smooth analog steering which is patched into one of the hacked joystick's axes. Two switches are used for the accelerator and brake and two additional buttons are mounted on the steering "wheel" that can be mapped to act as a handbrake, machine gun, etc. In one car, rumble motors attached to the steering wheel can also be connected to provide haptic feedback.

Controllers were also constructed from bamboo, which is a cheap, strong, abundant, easily repairable, readily available, easy to work with and culturally appropriate building material in South-east Asia. Students within the faculty were encouraged to get involved and help build the cars as an extra-curricular activity. The cars have been used at university game days, in local schools, at events to promote the university and in a local orphanage as part of student community service days.

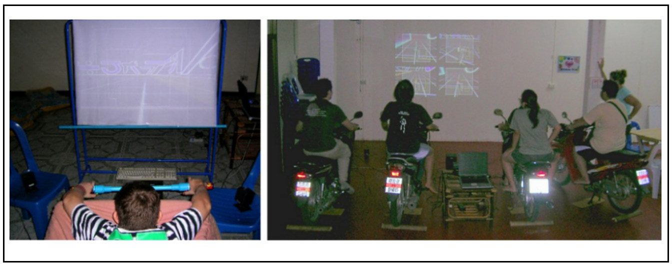

Figure 5. A single player light-cycle game controller made from PVC water-pipe (left) and a multi-player light-cycle game using real motorbikes (right).

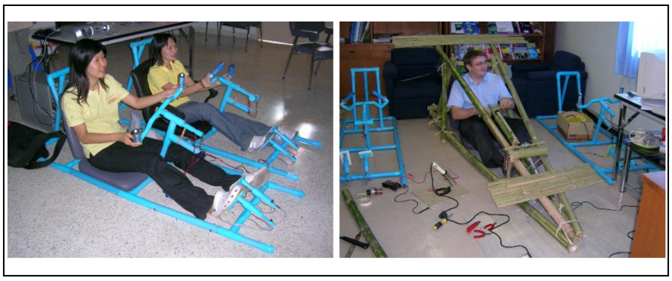

Figure 6. Racing game controllers made from PVC water-pipe (left) and bamboo (right).

Again, students need to consider the human at the center of these experiences and the chassis of the PVC racing cars consists of a series of sleeves and the length of the steering column on the bamboo racing car can be adjusted to accommodate drivers of different heights [14].

E. *Multi-player Guitar Hero and Quiz Games*

During science week at one the local schools more than 1,400 students were expected to participate in the event over 2 days. Two students at a time can race using the PVC water-pipe cars and four students can play a game of virtual pinball but there is only a small amount of time that students are willing to queue and wait for a game. A solution was to hack the Dualshock controllers for the music simulation game Guitar Hero [15]. The game is normally played with a plastic guitar-shaped controller where one player presses five coloured buttons in time to music and two players can compete at the same time. Using the hack described in Section II the controllers were modified so that five students can have one coloured button each and this allows up to ten students to play at the same time in two-player mode. See Fig. 7. Using modding tools the graphics of the game were customised to promote the university and the game has now been played by thousands of players in local schools, at English parties and orphanages.

The multi-player Guitar Hero button hardware has also been re-used with hacked USB joysticks to build a quiz game that has been used with freshman students, buzzers for judging a university talent quest, and a voting machine. Using USB-

Figure 7. Thai school students playing multi-player Guitar Hero during science week.

sniffing tools students are taught reverse engineering principles as they examine the serial communications between the computer and the joystick. They must then deduce how to read the button and joystick input and also how to control the rumble motors. This provides both the consolidation of programming knowledge about concepts like bit-masks and bit-shifting operations while also providing experience with serial communications programming and exposure to the USB model.

F. *Student Projects*

Some of the student projects created during the subject include a chording keyboard made from a pizza box for use in real time strategy games, a balance board joystick, a basketball trackball made using an optical mouse and deodorant rollers, and an IR light-gun for playing first-person perspective rail shooting games. Again, the projects required students to consider useability, HCI, and human factors principles. A balance board joystick, for example, needs to provide a comfortable range of movement for a seated player, while a controller that provides single-hand keyboard access to multiple in-game functions via chording needs both appropriate button spacing for different sized users as well as combinations that will be easily remembered by players.

V. Conclusion

This paper has described experiences using hacked game controllers to engage learners both inside and outside the classroom and these projects continue to be used both within the university and wider community. They provide novel ways to engage both existing and potential students through a wide range of hands-on experiences that can also be used to promote the university.

In particular, the hacked USB joystick has been presented as a cheap, plug-and-play interface platform. The gaming experiences enabled by these controllers combine software with everyday items like PVC water-pipe, bamboo, and pizza boxes. These experiences help those who encounter them to see the world around them differently.

Future directions for this work include a student project to integrate a hacked joystick with galvanic skin response sensors to create an experience similar to a Mindball game table for a fraction of the cost [16]. USB-powered rumble motors can be used to move the ball using a cable with a magnet and the joysticks button and analog inputs can be used to detect the ball position and provide player input.

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