

Hanoi University of Science and Technology

School of Information and Communication Technology



Project Report: Game Tetris using STM32CubeIDE hardware and software

IT4210E - Embedded Systems

Group Members:

Group 5 - Class: 161346
Luong Ngoc Vu Long - 20235967
Tran Sy Nguyen - 20235985
Nguyen Vu Anh Khoa - 20235957

Lecturers:

Prof. Ngô Lam Trung

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Contents

1	Introduction	2
1.1	Project Goals	2
1.2	Project Scope	2
2	Hardware Design	2
2.1	Development Board Specifications	3
2.2	Peripheral Configuration	3
2.2.1	Display Subsystem (LTDC & DMA2D)	4
2.2.2	Audio Subsystem (PWM)	4
2.2.3	Input Controls (GPIO & EXTI)	5
2.3	Random Number Generator (RNG)	5
3	Software Design	5
3.1	Model-View-Presenter (MVP) Architecture	5
3.2	The View: User Interface	6
3.2.1	Main Menu	6
3.2.2	Game Screen	6
3.3	The Presenter: Logic-UI Synchronization	7
3.3.1	MainViewPresenter	7
3.3.2	GameViewPresenter	7
3.4	The Model: Game Logic	7
3.4.1	Grid Representation	7
3.4.2	Game Loop ('tick')	8
3.5	System Integration (RTOS & Audio)	8
3.5.1	FreeRTOS Task Management	8
3.5.2	Audio Engine	8
4	System Integration & Challenges	8
4.1	Clock Tree Configuration for RNG	8
4.2	Input Debouncing	9
5	Results and Conclusion	9
5.1	Project Outcomes	9
5.2	Future Improvements	10

1 Introduction

The "Embedded Tetris" project aims to replicate the classic arcade experience on the STM32F429I-DISCO development board. By leveraging the high-performance ARM Cortex-M4 microcontroller, this project demonstrates the capability of modern embedded systems to handle real-time game logic, fluid graphical rendering, and multi-tasking.

1.1 Project Goals

The primary objectives of this project are:

- **System Integration:** To successfully integrate FreeRTOS with the TouchGFX framework, creating a responsive and stable application environment where the GUI task and background logic run concurrently.
- **Game Fidelity:** To implement the full functionality of the classic Tetris game, including:
 - **Tetromino Logic:** Spawning of all seven standard Tetromino types (I, J, L, O, S, T, Z) with randomized generation.
 - **Movement and Rotation:** Precise control for horizontal movement, soft dropping, and piece rotation with collision detection.
 - **Matrix Management:** A 10x20 grid system for tracking settled pieces, performing line detection, and implementing line clearing.
 - **Scoring and Progression:** A scoring system based on line clears and a leveling system that increases game speed to provide progressive difficulty.
 - **User Experience:** Integration of a "Hold" piece mechanism, "Next" piece preview, and high score tracking for a complete gameplay experience.

1.2 Project Scope

This project is confined to the following boundaries:

- **Hardware:** Strictly targeted for the STM32F429I-DISCO kit (STM32F429ZIT6 MCU).
- **Input:** Control is limited to the on-board user button and external push buttons (via GPIO), or the capacitive touch screen.
- **Output:** Visual elements are rendered on the built-in 2.4" QVGA display, and audio is output via a piezo buzzer connected to a PWM pin.
- **Software:** The codebase is built using STM32CubeIDE, utilising the HAL library for hardware abstraction and FreeRTOS for task scheduling.

2 Hardware Design

2.1 Development Board Specifications

The project utilizes the STM32F429I-DISCO kit, which is built around the STM32F429ZIT6 microcontroller. Key specifications utilized in this project include:

- **Core:** ARM Cortex-M4 with FPU, running at 168 MHz (configured via PLL).
- **Flash Memory:** 2 MB (Storing code and const assets like fonts/images).
- **RAM:** 256 KB Internal SRAM + 64 Mbits External SDRAM (used for Frame Buffers).
- **Display:** 2.4" QVGA TFT LCD via LTDC interface.

2.2 Peripheral Configuration

The hardware configuration is generated using STM32CubeMX (inside STM32CubeIDE).

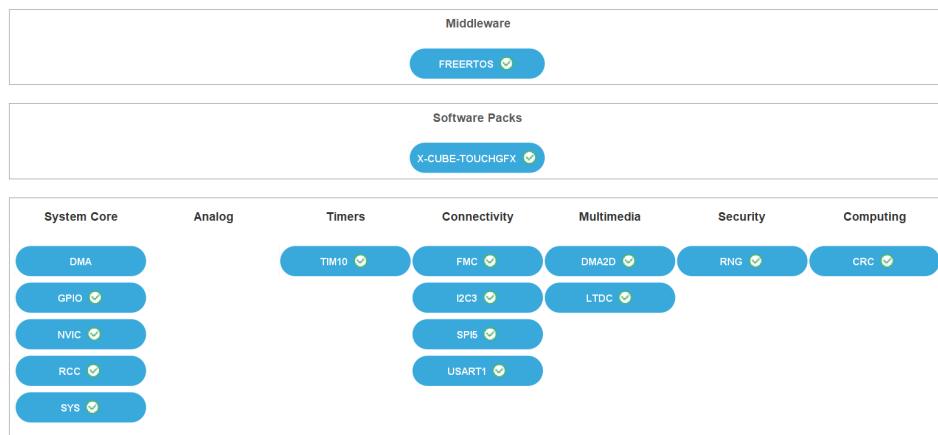


Figure 1: STM32CubeMX System and Peripheral Initialization Overview

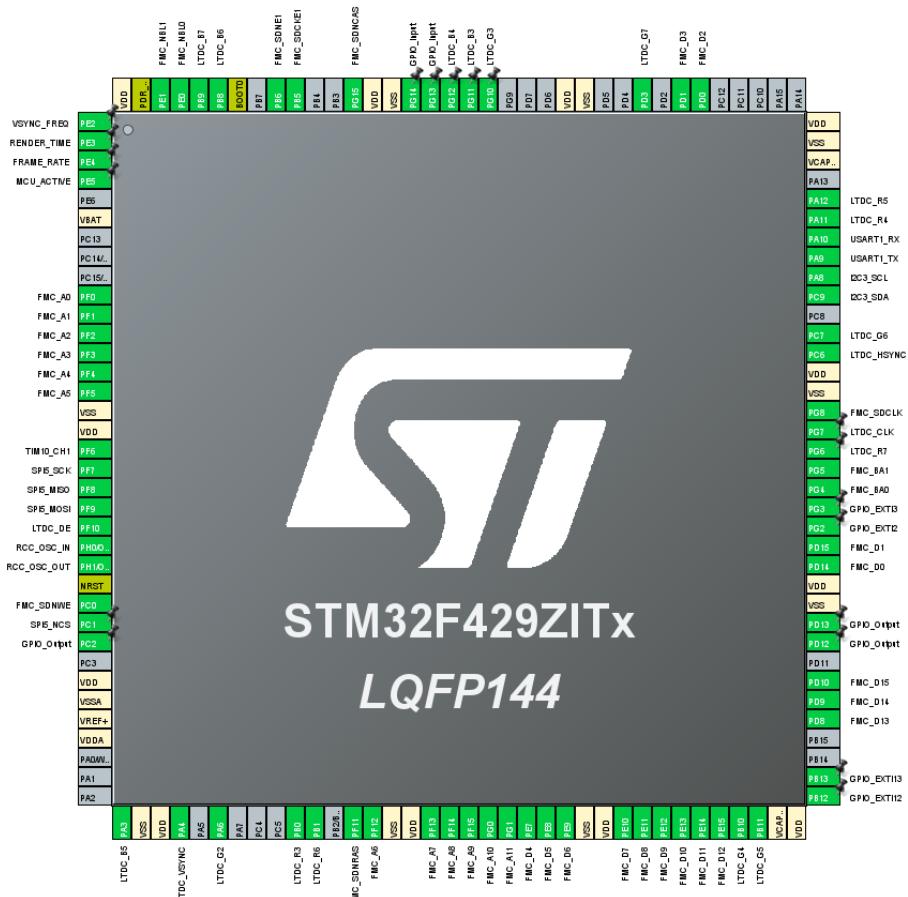


Figure 2: STM32F429ZIT6 Pinout and GPIO Configuration

2.2.1 Display Subsystem (LTDC & DMA2D)

The Liquid Crystal Display (LCD) is driven by the LTDC (LCD-TFT Display Controller) peripheral.

- **Interface:** RGB565 (16-bit color depth).
 - **Resolution:** 240 x 320 pixels.
 - **Memory:** Two frame buffers are allocated in the external SDRAM to support double buffering, preventing screen tearing.
 - **DMA2D:** Chrom-Art Accelerator is enabled to handle image copying and blending efficiently, offloading the CPU.

2.2.2 Audio Subsystem (PWM)

Sound generation is achieved using Pulse Width Modulation (PWM) connected to a Piezo Buzzer.

- **Timer:** TIM10.
 - **Channel:** Channel 1.
 - **Prescaler:** 167 (resulting in a 1 MHz timer clock).

- **Logic:** The frequency of the PWM signal controls the musical pitch (Note), and the duty cycle controls the volume.

2.2.3 Input Controls (GPIO & EXTI)

The game is controlled via four external push buttons connected to GPIO pins configured as external interrupts (EXTI).

Function	Pin	Port	Mode
Rotate Piece	Pin 12	GPIOB	EXTI Rising/Falling
Move Right	Pin 13	GPIOB	EXTI Rising/Falling
Soft Drop	Pin 2	GPIOG	EXTI Rising/Falling
Move Left	Pin 3	GPIOG	EXTI Rising/Falling

Table 1: GPIO Pin Mapping for Game Controls

2.3 Random Number Generator (RNG)

To ensure fair and unpredictable gameplay, the hardware Tetromino generation relies on the STM32's built-in Random Number Generator (RNG) peripheral. The peripheral requires a precise 48 MHz clock (PLL48CLK) and is configured to provide entropy for the piece spawning logic. Detailed implementation challenges regarding the clock tree configuration are discussed in Section 4.1.

3 Software Design

3.1 Model-View-Presenter (MVP) Architecture

The software architecture is centered around the Model-View-Presenter (MVP) pattern provided by the TouchGFX framework. This pattern ensures a strict separation of concerns between the visual interface, the underlying game logic, and the synchronization layer that connects them.

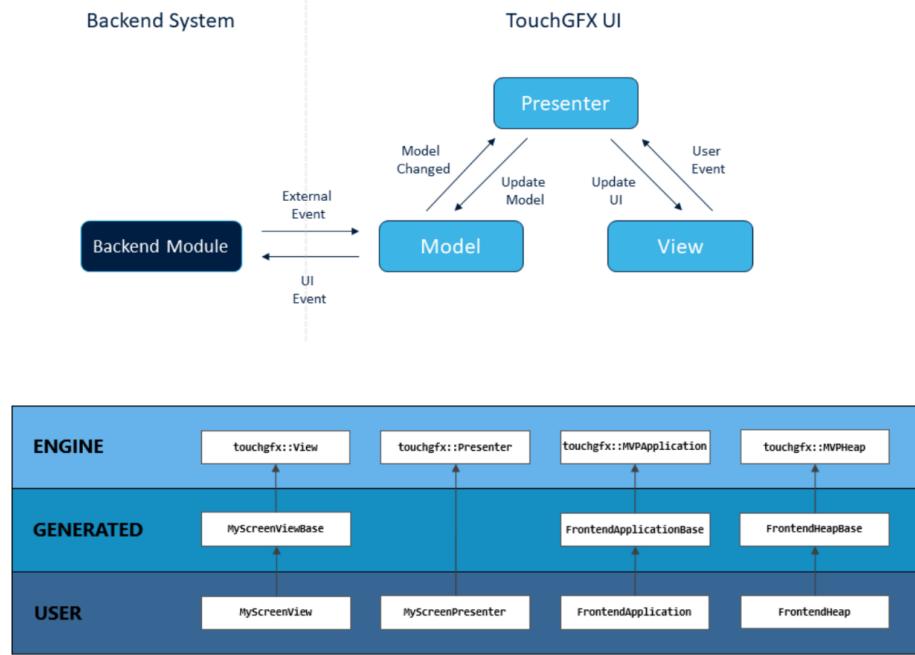


Figure 3: TouchGFX MVP Architecture and Class Hierarchy

- **View:** Responsible for the visual representation and layout.
- **Model:** Contains the core game state, rules, and mathematical logic.
- **Presenter:** Acts as the mediator, handling events from the View and updating the Model, or reflecting Model changes back to the View.

3.2 The View: User Interface

The View layer is implemented using C++ classes generated by TouchGFX. It focuses on rendering the graphical assets and handling the screen layout for the 240x320 portrait display.

3.2.1 Main Menu

Displays the "Tetris Art" logo and options to start the game. The background plays a slower, ambient menu theme.

3.2.2 Game Screen

The layout is optimized for the portrait screen, dividing the interface into functional zones:

- Center: 10x20 Game Matrix showing active and resting Tetrominos.
- Left Sidebar: HOLD piece slot and Level indicator.
- Right Sidebar: NEXT piece preview and Score display.

3.3 The Presenter: Logic-UI Synchronization

The Presenter layer serves as the bridge between the View and the Model. It listens for notifications from the Model (via ‘ModelListener’) and triggers updates in the View, ensuring the visual layer stays perfectly synchronized with the logical state. This project utilizes two distinct presenters corresponding to the two main screens.

3.3.1 MainViewPresenter

The ‘MainViewPresenter’ manages the logic for the Main Menu screen. Its responsibilities are streamlined to focus on navigation and data retrieval for the menu interface:

- ****Navigation:**** Handles the transition event when the user selects "Start Game", requesting the application to switch to the Game Screen.
- ****Data Retrieval:**** Fetches stored high scores from the Model (‘getHighScores’) to display the leaderboard on the menu, enticing the player to beat the top records.

3.3.2 GameViewPresenter

The ‘GameViewPresenter’ is the core mediator for the active gameplay session. It handles a high frequency of events and data flow:

- ****Input Proxying:**** It receives user input events from the View (e.g., button presses for left, right, rotate) and forwards them to the Model via methods like ‘handleLeft()’ or ‘handleRotate()’.
- ****State Synchronization:**** It implements the ‘modelStateChanged()’ method. When the game tick updates the Model (gravity, collisions), this method is called to trigger ‘view.updateBoard()’, ensuring the screen redraws at 60 FPS.
- ****Scoreboard Logic:**** It implements complex logic for the Game Over screen. The ‘getScoreboard()’ method retrieves the top 3 high scores, mixes in the current player’s score, and sorts them dynamically. This allows the player to see their rank immediately upon finishing a game (‘ScoreInfo’ structure).

```
1 // Example: Synchronization in GameViewPresenter.cpp
2 void GameViewPresenter::modelStateChanged()
3 {
4     view.updateBoard(); // Signal the View to redraw based on new Model
5     data
```

3.4 The Model: Game Logic

The Model layer maintains the internal state of the Tetris grid and implements the rules of the game. It is independent of the GUI framework, allowing for easier testing and logic updates.

3.4.1 Grid Representation

The 10x20 game board is represented as a 2D array: ‘signed char grid[20][10]’, where each cell stores a value corresponding to a Tetromino type or remains -1 if empty.

3.4.2 Game Loop ('tick')

The 'tick()' function is the entry point for game updates, called every frame (60Hz). It handles gravity, collision detection via 'isCollision()', and line clearing logic.

```
1 void Model::tick()
2 {
3     if (isGameOver || isPaused) return;
4
5     tickCounter++;
6     if (tickCounter >= dropSpeed)
7     {
8         tickCounter = 0;
9         step(); // Gravity drop
10    }
11   // ... Input queue processing ...
12 }
```

3.5 System Integration (RTOS & Audio)

The application logic sits atop a real-time foundation that manages hardware resources and asynchronous background tasks.

3.5.1 FreeRTOS Task Management

Three primary tasks ensure smooth operation:

- **GUI_Task:** Executes the TouchGFX engine and MVP logic (High Priority).
- **DefaultTask:** Handles button debouncing and system monitoring.
- **SoundTask:** Processes audio requests in the background (Low Priority).

3.5.2 Audio Engine

To maintain performance, audio is handled via a Producer-Consumer pattern. The Game Model (Producer) sends 'TrackID' requests to a queue, which are processed by the 'SoundTask' (Consumer) to drive the PWM-based buzzer.

4 System Integration & Challenges

4.1 Clock Tree Configuration for RNG

A significant challenge during hardware integration was the 48 MHz clock requirement for the RNG. The STM32F429 reaches its maximum performance at a SysClk of 180 MHz, but the Main PLL cannot generate both 180 MHz and 48 MHz simultaneously due to integer divider limitations.

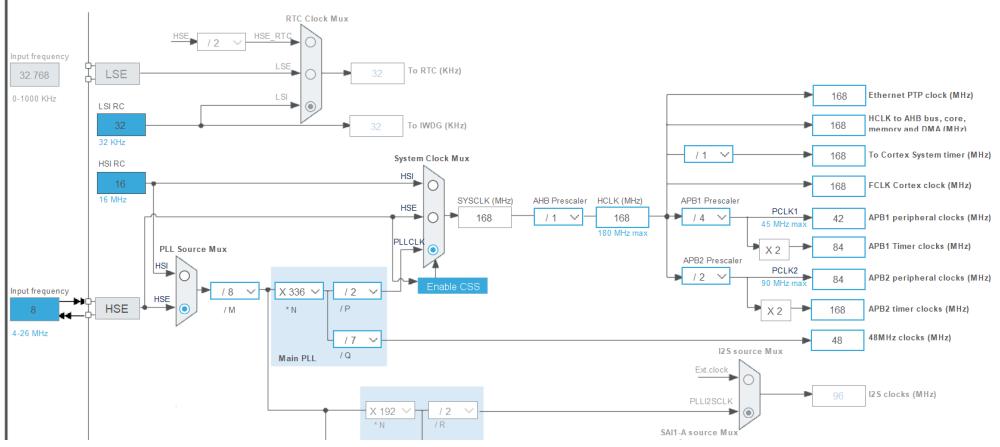


Figure 4: Final Clock Configuration (168 MHz SysClk, 48 MHz PLL48CLK)

- **The Issue:** At 180 MHz (VCO = 360 MHz), the PLLQ divider would need to be 7.5 to reach 48 MHz, which is not supported. Deviations from 48 MHz lead to peripheral initialization failure and "Clock Error" flags.
- **The Solution:** We adjusted the system clock to 168 MHz (PLLM=8, PLLN=336, PLLP=2, PLLQ=7).
- **VCO Calculation:** $(8 \text{ MHz}/8) \times 336 = 336 \text{ MHz}$.
- **Resulting Clocks:** SysClk = $336 \text{ MHz}/2 = 168 \text{ MHz}$; RNG Clock = $336 \text{ MHz}/7 = 48 \text{ MHz}$ (Exact).

4.2 Input Debouncing

Directly reading GPIO pins caused erratic behavior due to mechanical switch bounce. We implemented software debouncing using FreeRTOS Timers.

- When a button press interrupt occurs, a timer starts (e.g., 50ms).
- The input is only registered if the signal remains stable until the timer callback executes.

5 Results and Conclusion

5.1 Project Outcomes

The project successfully delivers a playable Tetris clone on the STM32F429I-DISCO.

- Performance: The game runs at a stable 60 FPS.
- Audio: Background music plays smoothly without interrupting game logic.
- Gameplay: All standard Tetris rules (rotation, wall kicks, line clears, leveling) are implemented.

5.2 Future Improvements

- Implement "Ghost Piece" visualization (indicated in design but currently simplified).
- Save high scores to internal Flash memory to persist after power loss.
- Add support for using the on-board Gyroscope (SPI5) for experimental tilt controls.